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ON LIGHT AND OTHER HIGH FREQUENCY PHENOMENA.*

BY NIKOLA TESLA.

[*Continued from p. 19.*]

It is desirable, in order to maintain the vibration economically, to reduce the impact and frictional losses as much as possible. As regards the latter, which in the electrical analogue correspond to the losses due to the resistance of the circuits, it is impossible to obviate them entirely, but they can be reduced to a minimum by a proper selection of the dimensions of the circuits and by the employment of thin conductors in the form of strands. But the loss of energy caused by the first breaking through of the dielectric—which

* A lecture delivered before the Franklin Institute, at Philadelphia, February 24, 1893, and before the National Electric Light Association, at St. Louis, March 1, 1893.

in the above example corresponds to the violent knock of the bottom against the inelastic stop—would be more important to overcome. At the moment of the breaking through, the air space has a very high resistance, which is probably reduced to a very small value when the current has reached some strength, and the space is brought to a high temperature. It would materially diminish the loss of energy, if the space were always kept at an extremely high temperature, but then there would be no disruptive break. By warming the space moderately by means of a lamp or otherwise, the economy, as far as the arc is concerned, is sensibly increased. But the magnet or other interrupting device does not diminish the loss in the arc. Likewise, a jet of air only facilitates the carrying off of the energy. Air, or a gas in general, behaves curiously in this respect.

When two bodies, charged to a very high potential, discharge disruptively through an air space, any amount of energy may be carried off by the air. This energy is evidently dissipated by bodily carriers, in impact and collisional losses of the molecules. The exchange of the molecules in the space occurs with inconceivable rapidity. When a powerful discharge takes place between two electrodes, they may remain entirely cool, and yet the loss in the air may represent any amount of energy. It is quite practicable, with very great potential differences in the gap, to dissipate several horse-power in the arc of the discharge without even noticing a small increase in the temperature of the electrodes. All the frictional losses occur then practically in the air. If the exchange of the air molecules is prevented, as by enclosing the air hermetically, the gas inside of the vessel is brought quickly to a high temperature, even with a very small discharge. It is difficult to estimate how much of the energy is lost in sound waves, audible or not, in a powerful discharge. When the currents through the gap are large, the electrodes may become rapidly heated, but this is not a reliable measure of the energy wasted in the arc, as the loss through the gap itself may be comparatively small. The air, or a gas in general, is, at ordinary pressures at least, clearly not the best medium through

which a disruptive discharge should occur. Air or other gas under great pressure is of course a much more suitable medium for the discharge gap. I have carried on long-continued experiments in this direction, unfortunately less practicable on account of the difficulties and expense in getting air under great pressure. But whether the medium in the discharge space be solid or liquid, the same losses take place, though they are generally smaller, for just as soon as the arc is established, the solid or liquid is volatilized. Indeed, there is no body known which would not be disintegrated by the arc, and it is an open question among scientific men, whether an arc discharge could occur at all in the air itself without the particles of the electrodes being torn off. When the current through the gap is very small and the arc very long, I believe that a relatively considerable amount of heat is taken up in the disintegration of the electrodes, which partially on this account may remain quite cold.

The ideal medium for a discharge gap should only *crack*, and the ideal electrode should be of some material which cannot be disintegrated. With small currents through the gap it is best to employ aluminum, but not when the currents are large. The disruptive break in the air, or in any ordinary medium, is not of the nature of a crack, but it is rather comparable to the piercing of innumerable bullets through a mass offering great frictional resistance to the motion of the bullets, thus involving considerable loss of energy. A medium which would merely crack when strained electrostatically—and this possibly might be the case with a perfect vacuum; that is, in pure ether—would involve a very small loss in the gap, so small as to be entirely negligible, at least theoretically, because a crack may be produced by an infinitely small displacement. In exhausting, with the greatest care, an oblong bulb provided with two aluminum terminals, I have succeeded in producing so high a vacuum that the secondary discharge of a disruptive discharge coil would break through disruptively through the bulb in the form of fine spark streams. The curious point was that the discharge would completely

ignore the terminals and start far behind the two aluminum plates which served as electrodes. This extraordinarily high vacuum could only be maintained for a very short time.

To return to the ideal medium, think, for the sake of illustration, of a piece of glass or similar body clamped in a vise, and the latter tightened more and more. At a certain point a minute increase of the pressure will cause the glass to crack. The loss of energy involved in splitting the glass may be practically nothing, for though the force is great, the displacement need be but extremely small. Now imagine that the glass possesses the property of perfectly closing the crack upon a minute diminution of the pressure. This is the way the dielectric in the discharge space should behave. But inasmuch as there would be always some loss in the gap, the medium which should be continuous should exchange through the gap at a rapid rate.

In the preceding example, the glass being perfectly closed, it would mean that the dielectric in the discharge space possesses a great insulating power; the glass being cracked, it would signify that the medium in the space is a good conductor. The dielectric should vary enormously in resistance by minute variations of the E. M. F. across the discharge space. This condition is attained, but in an extremely imperfect manner, by warming the air space to a certain critical temperature, dependent on the E. M. F. across the gap, or by otherwise impairing the insulating power of the air. But as a matter of fact the air never breaks down *disruptively*, if this term be rigorously interpreted, for before the sudden rush of the current occurs, there is always a weak current preceding it, which rises first gradually and then with comparative suddenness. That is the reason why the rate of change is very much greater when glass, for instance, is broken through, than when the break takes place through an air space of equivalent dielectric strength. As a medium for the discharge space a solid, or even a liquid would be preferable. It is somewhat difficult to conceive of a solid body which

would possess the property of closing instantly after it has been cracked. But a liquid, especially under great pressure, behaves practically like a solid, while it possesses the property of closing the crack. Hence it was thought that a liquid insulator might be more suitable as a dielectric than air. Following out this idea, a number of different forms of dischargers, in which a variety of such insulators, sometimes under great pressure, were employed, have been tried. It is thought sufficient to dwell in a few words upon one of the forms experimented upon. One of these dischargers is illustrated in *Figs. 4a* and *4b*.

A hollow metal pulley *P*, (*Fig. 4a*,) was fastened upon an arbor *a*, which by a suitable means was rotated at a considerable speed. In the inside of the pulley, but disconnected from the same, was supported a thin disc h_1 (which is

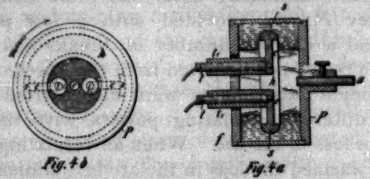


Fig. 4b *Fig. 4a*

Form of discharger with liquid interrupter.

shown thick for the sake of clearness) of hard rubber, in which there were embedded two metal segments *s s*, with metallic extensions *e e*, into which were screwed conducting terminals *t t*, covered with thick tubes of hard rubber *t t*. The rubber disc *h*, with its metallic segments *s s*, was finished in a lathe, and its entire surface highly polished so as to offer the smallest possible frictional resistance to motion through a fluid. In the hollow of the pulley an insulating liquid, such as a thin oil, was poured so as to reach very nearly to the opening left in the flange *f*, which was screwed tightly on the front side of the pulley. The terminals *t t* were connected to the opposite coatings of a battery of condensers so that the discharge occurred through the liquid. When the pulley was rotated the liquid was forced against the rim of the pulley and con-

siderable fluid pressure resulted. In this simple way the discharge gap was filled with a medium which behaved practically like a solid, which possessed the quality of closing instantly upon the occurrence of the break, and which moreover was circulating through the gap at a rapid rate.

Very powerful effects were produced by dischargers of this kind with liquid interrupters, of which a number of different forms were made. It was found, as expected, that a longer spark for a given length of wire was obtainable in this way than by using air as an interrupting device. In the form of discharger described, the speed, and, therefore, also the fluid pressure, were limited by reason of the fluid friction, but the practically obtainable speed was more than sufficient to produce a number of breaks suitable for the circuits ordinarily used. In some instances the metal pulley *P*, was provided with a few projections inwardly, and a definite number of breaks was then produced which could be computed from the speed of rotation of the pulley. Experiments were also carried on with liquids of different insulating powers, with the view of reducing the loss in the arc. When an insulating liquid is moderately warmed the loss in the arc is diminished.

A point of some importance was noted in experiments with various dischargers of this kind. It was found, for instance, that, whereas the conditions maintained in these forms were favorable for the production of a great spark length, the current so obtained were not best suited to the production of light effects. Experience undoubtedly has shown, that for such purpose a harmonic rise and fall of the potential is preferable. Whether it be that a solid is rendered incandescent, or phosphorescent, or that energy is transmitted by the condenser coating through the glass, it is certain that a harmonically rising and falling potential produces less destructive action, and that the vacuum is more permanently maintained. This would be easily explained if it were ascertained that the process going on in an exhausted vessel is of an electrolytic nature.

In the diagrammatical sketch, *Fig. 1*, which has already

been referred to, the cases which are most likely to be met with in practice are illustrated. One has at his disposal either direct or alternating currents from a supply station. It is convenient for an experimenter in an isolated laboratory, to employ a machine *G*, such as illustrated, capable of giving both kinds of currents. In such case it is also preferable to use a machine with multiple circuits, as in many experiments it is useful and convenient to have at one's disposal currents of different phases. In the sketch, *D* represents the direct, and *A*, the alternating circuit. In each of these, three branch circuits are shown, all of which are provided with double line switches, *s s s s s s*. Consider first, the direct current conversion; *1a* represents the simplest case. If the E. M. F. of the generator is sufficient to break through a small air space, at least when the latter is warmed or otherwise rendered poorly insulating, there is no difficulty in maintaining a vibration with fair economy by judicious adjustment of the capacity, self-induction and resistance of the circuit *L* containing the devices *l l m*. The magnet *N S*, in this case, can advantageously be combined with the air space. The discharger *d d*, with the magnet, may be placed either way, as indicated by the full, or by the dotted, lines. The circuit *1a* with the connections and devices is supposed to possess dimensions such as are suitable for the maintenance of a vibration. But usually the E. M. F. on the circuit or branch *1a* will be something like 100 volts or so, and in this case it is not sufficient to break through the gap. Many different means may be used to remedy this by raising the E. M. F. across the gap. The simplest is probably to insert a large self-induction coil in series with the circuit *L*. When the arc is established, as by the discharger illustrated in *Fig. 2*, the magnet blows the arc out the instant it is formed. Now the extra current of the break, being of high E. M. F., breaks through the gap, and a path of low resistance for the dynamo current being again provided, there is a sudden rush of the current from the dynamo upon the weakening or subsidence of the extra current. This process is repeated in rapid succession, and in this manner I have maintained

oscillation with as low as fifty volts, or even less, across the gap. But conversion on this plan is not to be recommended on account of the too heavy currents through the gap and consequent heating of the electrodes; besides, the frequencies obtained in this way are low, owing to the high self-induction necessarily associated with the circuit. It is very desirable to have the E. M. F. as high as possible, firstly, in order to increase the economy of the conversion; and, secondly, to obtain high frequencies. The difference of potential in this electric oscillation is, of course, the equivalent of the stretching force in the mechanical vibration of the spring. To obtain very rapid vibration in a circuit of some inertia, a great stretching force or difference of potential is necessary. Incidentally, when the E. M. F. is very great, the condenser which is usually employed in connection with the circuit need have but a small capacity, and many other advantages are gained. With a view of raising the E. M. F. to a many times greater value than that obtainable from ordinary distribution circuits, a rotating transformer *g* is used, as indicated in *Fig. 2a*, or else a separate high potential machine is driven by means of a motor operated from the generator *G*. The latter plan is in fact preferable, as changes are more easily made. The connections from the high tension winding are quite similar to those in branch *1a*, with the exception that a condenser *C*, which should be adjustable, is connected to the high tension circuit. Usually, also, an adjustable self-induction coil in series with the circuit has been employed in these experiments. When the tension of the currents is very high the magnet ordinarily used in connection with the discharger is of comparatively small value, as it is quite easy to adjust the dimensions of the circuit so that oscillation is maintained.

The employment of a steady E. M. F. in the high frequency conversion affords some advantages over the employment of alternating E. M. F., as the adjustments are much simpler and the action can be more easily controlled. But unfortunately one is limited by the obtainable potential difference. The windings also break down easily in consequence of the sparks which form between the sections of the armature

or commutator when a vigorous oscillation takes place. Besides, these transformers are expensive to build. It has been found by experience that it is best to follow the plan illustrated in *Fig. 3a*. In this arrangement a rotating transformer *g* is employed to convert the low tension direct currents into low frequency alternating currents, preferably also of small tension. The tension of the currents is then raised in a stationary transformer *T*. The secondary *S* of this transformer is connected to an adjustable condenser *C*, which discharges through the gap or discharger *d d*, placed in either of the ways indicated, through the primary *P* of a disruptive discharge coil, the high frequency currents being obtained from the secondary *S* of this coil, as described on previous occasions. This will undoubtedly be found the cheapest and most convenient way of converting direct currents.

The three branches of the circuit *A*, represent the usual cases met in practice when alternating currents are converted. In *Fig. 1b*, a condenser *C*, generally of large capacity, is connected to the circuit *L*, containing the devices *l l m m*. The devices *m m* are supposed to be of high self-induction so as to bring the frequency of the circuit more or less to that of the dynamo. In this instance the discharger *d d* should best have a number of makes and breaks per second equal to twice the frequency of the dynamo. If not so, then it should have at least a number equal to a multiple or even a fraction of the dynamo frequency. It should be observed, referring to *1b*, that the conversion to a high potential is also affected when the discharger *d d*, which is shown in the sketch, is omitted. But the effects which are produced by currents which rise instantly to high values, as in a disruptive discharge, are entirely different from those produced by dynamo currents which rise and fall harmonically. So, for instance, there might be, in a given case, a number of makes and breaks at *d d*, equal to just twice the frequency of the dynamo, or in other words there may be the same number of fundamental oscillations as would be produced without the discharge gap, and there might even not be any quicker superimposed vibration; yet

the differences of potential at the various points of the circuit, the impedence and other phenomena, dependent upon the rate of change, will bear no similarity in the two cases. Thus, when working with currents discharging disruptively, the element chiefly to be considered, is not the frequency, as a student might be apt to believe, but the rate of change per unit of time. With low frequencies, in a certain measure, the same effects may be obtained as with high frequencies, provided the rate of change is sufficiently great. So, if a low frequency current is raised to a potential of (say) 75,000 volts and the high tension current passed through a series of high resistance lamp filaments, the importance of the rarefied gas surrounding the filament is clearly noted, as will be seen later; or, if a low frequency current of several thousand ampères is passed through a metal bar, striking phenomena of impedence are observed, just as with currents of high frequencies. But it is, of course, evident that with low frequency currents, it is impossible to obtain such rates of change per unit of time as with high frequencies, hence the effects produced by the latter are much more prominent. It was deemed advisable to make the preceding remarks, inasmuch as many more recently described effects have been unwittingly identified with high frequencies. Frequency alone in reality does not mean anything, except when an undisturbed harmonic oscillation is considered.

In the branch *3b*, a similar disposition as in *1b*, is illustrated, with the difference that the currents discharging through the gap *d d* are used to induce currents in the secondary *S* of a transformer *T*. In such case the secondary should be provided with an adjustable condenser for the purpose of tuning it to the primary.

Fig. 2b illustrates a plan of alternate current high frequency conversion which is most frequently used and which is found to be most convenient. This plan has been dwelt upon in detail on previous occasions and need not be described here.

Some of these results were obtained by the use of a high frequency alternator. A description of such machines will

be found in my original paper before the American Institute of Electrical Engineers, and in the periodicals of that period, notably in *The Electrical Engineer*, of March 18, 1891.

I will now proceed with the experiments:

On Phenomena produced by Electrostatic Force.—The first class of effects I intend to show you, are effects produced by electrostatic force. It is the force which governs the motion of the atoms, which causes them to collide and develop the life-sustaining energy of heat and light, and which causes them to aggregate in an infinite variety of ways, according to nature's fanciful designs, and to form all these wondrous structures we perceive around us; it is, in fact, if our present views be true, the most important force in nature for us to consider. As the term *electrostatic* might imply a steady electric condition, it should be remarked, that in these experiments the force is not constant, but varies at a rate which may be considered moderate, about 1,000,000 times a second, or thereabouts. This enables me to produce many effects which are not producible with an unvarying force.

When two conducting bodies are insulated and electrified, we say that an electrostatic force is acting between them. This force manifests itself in attractions, repulsions and stresses in the bodies and in the space or medium without. So great may be the strain exerted in the air, or whatever separates the two conducting bodies, that it may break down, and we observe sparks or bundles of light, or streamers, as they are called. These streamers form abundantly when the force through the air is rapidly varying. I will illustrate this action of electrostatic force in a novel experiment in which I will employ the induction coil before referred to. The coil is contained in a trough filled with oil, and placed under the table. The two ends of the secondary wire pass through the two thick columns of hard rubber, which protrude to some height above the table. It is necessary to insulate heavily the ends or terminals of the secondary with hard rubber, because even dry wood is by far too poor an insulator for these currents of enormous potential differences. On one of the terminals of the coil, I have placed

a large sphere of sheet brass, which is connected to a larger insulated brass plate, in order to enable me to perform the experiments under conditions, which, as you will see, are more suitable for this experiment. I now set the coil to work and approach the free terminal with a metallic object held in my hand; this, simply to avoid burns. As I approach the metallic object to a distance of eight or ten inches, a torrent of furious sparks breaks forth from the end of the secondary wire, which passes through the rubber column. The sparks cease when the metal in my hand touches the wire. My arm is now traversed by a powerful electric current, vibrating at about the rate of 1,000,000 times a second. All around me the electrostatic force makes itself felt, and the air molecules and particles of dust flying about are acted upon and are hammering violently against my body. So great is this agitation of the particles, that when the lights are turned out you may see streams of feeble light appear on some parts of my body. When such a streamer breaks out on any part of the body, it produces a sensation like the pricking of a needle. Were the potentials sufficiently high and the frequency of the vibration rather low, the skin would probably be ruptured under the tremendous strain, and the blood would rush out with great force in the form of fine spray, or jet, so thin as to be invisible, just as oil will when placed on the positive terminal of a Holtz machine. This breaking through of the skin, though it may seem impossible at first, would perhaps occur, by reason of the tissues under the skin being incomparably better conducting. This, at least, appears plausible, judging from some observations.

I can make these streams of light visible to all, by touching with the metallic object one of the terminals as before, and approaching my free hand to the brass sphere, which is connected to the second terminal of the coil. As the hand is approached, the air between it and the sphere, or in the immediate neighborhood, is more violently agitated and you see streams of light now break forth from my finger tips and from the whole hand (*Fig. 5*). Were I to approach the hand closer, powerful sparks would jump from the brass

sphere to my hand, which might be injurious. The streamers offer no particular inconvenience, except that in the ends of the finger tips a burning sensation is felt. They should not be confounded with those produced by an influence machine, because, in many respects, they behave differently. I have attached the brass sphere and plate to one of the terminals in order to prevent the formation of visible streamers on that terminal, also, in order to prevent sparks from jumping to a considerable distance. Besides, the attachment is favorable for the working of the coil.

The streams of light, which you have observed issuing from my hand, are due to a potential of about 200,000 volts, alternating in rather irregular intervals, something like 1,000,000 times a second. A vibration of the same amplitude,

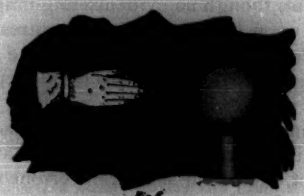


Fig 5

Illustrating the effect of varying electrostatic force with a transformer of 200,000 volts pressure.

but four times as fast to maintain which, over 3,000,000 volts would be required, would be more than sufficient to envelop my body in a complete sheet of flame. But this flame would not burn me up; quite the reverse, the probability is that I would not be injured in the least. Yet a hundredth part of that energy, otherwise directed, would be amply sufficient to kill a person.

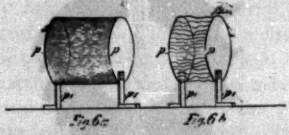
The amount of energy which may thus be passed into the body of a person depends on the frequency and potential of the currents, and by making both of these very great, a vast amount of energy may be passed into the body without causing any discomfort, except perhaps, in the arm, which is traversed by a true conduction current. The reason why no pain in the body is felt, and no injurious effect

noted, is, that everywhere, if a current be imagined to flow through the body, the direction of its flow would be at right angles to the surface; hence the body of the experimenter offers an enormous section to the current, and the density is very small, with the exception of the arm, perhaps, where the density may be considerable. But if only a small fraction of that energy would be applied in such a way that a current would traverse the body in the same manner as a low frequency current, a shock would be received which might be fatal. A direct or low frequency alternating current is fatal, I think, principally because its distribution through the body is not uniform, as it must divide itself in minute streamlets of great density, whereby some organs are vitally injured. That such a process occurs I have not the least doubt, though no evidence might apparently exist, or be found upon examination. The surest to injure and destroy life, is a continuous current, but the most painful is an alternating current of very low frequency. The expression of these views, which are the result of long-continued experiment and observation, both with steady and varying currents, is elicited by the interest which is at present taken in this subject, and by the manifestly erroneous ideas which are daily propounded in the journals.

I may illustrate an effect of the electrostatic force by another striking experiment, but before, I must call your attention to one or two facts. I have said before, that when the medium between two oppositely electrified bodies is strained beyond a certain limit, it gives way, and, stated in popular language, the opposite electric charges unite and neutralize each other. This breaking down of the medium occurs principally when the force acting between the bodies is steady, or varies at a moderate rate. Were the variation sufficiently rapid, such a destructive break would not occur, no matter how great the force, for all the energy would be spent in radiation, convection and mechanical and chemical action. Thus the *spark* length, or greatest distance through which a *spark* will jump between the electrified bodies is the smaller, the greater the variation or time rate of change. But this rule may be taken to be true only in a

general way, when comparing rates which are widely different.

I will show you by an experiment the difference in the effect produced by a rapidly varying, and a steady or moderately varying force. I have here two large circular brass plates *p p* (*Figs. 6a* and *6b*), supported on movable insulating stands on the table, and connected to the ends of the secondary of a similar coil as the one used before. I place the plates ten or twelve inches apart and set the coil to work. You see the whole space between the plates, nearly two cubic feet, filled with uniform light, *Fig. 6a*. This light is due to the streamers you have seen in the first experiment, which are now much more intense. I have already pointed out the importance of these streamers in commercial apparatus and their still greater importance in some



Illustrating the effects of rapidly varying and steady electrostatic force.

purely scientific investigations. Often they are too weak to be visible, but they always exist, consuming energy and modifying the action of the apparatus. When intense, as they are at present, they produce ozone in great quantity, and also, as Professor Crookes has pointed out, nitrous acid. So quick is the chemical action, that if a coil such as this one, is worked for a very long time it will make the atmosphere of a small room unbearable, for the eyes and throat are attacked. But when moderately produced, the streamers refresh the atmosphere wonderfully, like a thunder storm, and exercise unquestionably a wholesome effect.

In this experiment the force acting between the plates changes in intensity and direction at a very rapid rate. I will now make the rate of change per unit time much smaller. This I effect by rendering the discharges through the primary of the induction coil less frequent, and also by

diminishing the rapidity of the vibration in the secondary. The former result is conveniently secured by lowering the E. M. F. over the air gap in the primary circuit; the latter, by approaching the two brass plates to a distance of about three or four inches. When the coil is set to work you see no streamers or light between the plates, yet the medium between them is under a tremendous strain. I still further augment the strain by raising the E. M. F. in the primary circuit, and soon you see the air give way and the hall is illuminated by a shower of brilliant and noisy sparks, *Fig. 6b*. These sparks could be produced also with unvarying force; they have been for many years a familiar phenomenon, though they were usually obtained from entirely different

Breaking a bulb on open circuit.

apparatus. In describing these two phenomena, so radically different in appearance, I have advisedly spoken of a "force" acting between the plates. It would be in accordance with accepted views to say that there was an "alternating E. M. F." acting between the plates. This term is quite proper and applicable in all cases where there is evidence of at least a possibility of an essential interdependence of the electric state of the plates, or electric action in their neighborhood. But whether the plates be removed to an infinite distance, or to a finite distance, there is no probability or necessity whatever for such dependence. I prefer to use the term "electrostatic force," and to say that such a force is acting around each plate or electrified

insulated body in general. There is an inconvenience in using this expression as the term incidentally means a steady electric condition; but a proper nomenclature will eventually settle this difficulty.

I now return to the experiment to which I have already alluded, and with which I desire to illustrate a striking effect produced by a rapidly varying electrostatic force. I attach to the end of the wire *l* (*Fig. 7*), which is in connection with one of the terminals of the secondary of the induction coil, an exhausted bulb *b*. This bulb contains a thin carbon filament *f*, which is fastened to a platinum wire *w*, sealed in the glass and leading outside of the bulb, where it connects to the wire *l*. The bulb may be exhausted to any degree attainable with ordinary apparatus. Just a moment before, you have witnessed the breaking down of the air between the charged brass plates. You know that a plate of glass, or any other insulating material, would break down in like manner. Had I therefore a metallic coating attached to the outside of the bulb, or placed near the same, and were this coating connected to the other terminal of the coil, you would be prepared to see the glass give way if the strain were sufficiently increased. Even were the coating not connected to the other terminal, but to an insulated plate, still, if you have followed recent developments, you would naturally expect a rupture of the glass.

But it will certainly surprise you to note that under the action of the varying electrostatic force, the glass gives way when all other bodies are removed from the bulb. In fact, all the surrounding bodies we perceive might be removed to an infinite distance without affecting the result in the slightest. When the coil is set to work, the glass is invariably broken through at the seal, or other narrow channel, and the vacuum is quickly impaired. Such a damaging break would not occur with a steady force, even if the same were many times greater. The break is due to the agitation of the molecules of the gas within the bulb, and outside of the same. This agitation, which is generally most violent in the narrow pointed channel near the seal, causes a heating and rupture of the glass. This rupture would, how-

ever, not occur, not even with a varying force, if the medium filling the inside of the bulb, and that surrounding it, were perfectly homogeneous. The break occurs much more quickly if the top of the bulb is drawn out into a fine fibre. In bulbs used with these coils such narrow, pointed channels must therefore be avoided.

[*To be continued.*]

PRESENT DEVELOPMENT OF HEAVY ORDNANCE IN THE UNITED STATES.

By W. H. Jaques, Ordnance Engineer.

[*A lecture delivered before the Franklin Institute, January 6, 1893.*]

[*Concluded from p. 36.*]

Of the two systems of breech-loading in general use—the American-French interrupted screw and what is now familiary known as the Krupp wedge—the former is used by both branches of our military service.

While differing in details, the general operation is to unscrew the plug or breech screw, withdraw it, land and latch it on the tray, carrier or bracket (as this part is variously called), swing the tray on its hinge pin to one side and catch and hold it there during the operation of inserting the projectile and powder charge.

This view* shows the mechanism used by the Navy for the ten-inch and twelve-inch guns, when closed.

This view* the same when the breech is open.

The apparatus* employed by the Army is composed of a greater number of parts and is more complicated; but it works well and has a peculiar double-threaded shaft, by which increased power and speed are obtained for operating the breech-block.

* Lantern view.

Of the many hundreds of devices that have been proposed for the closing and gas-checking of breech-loading ordnance, the most effective at the present time are the Canet-Whitworth breech mechanisms, *Figs. 2* and *3*, and the de Bange gas check. Their chief advantages are strength, simplicity,

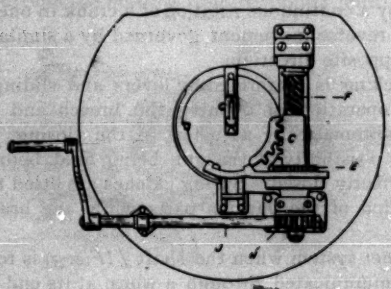


FIG. 2.

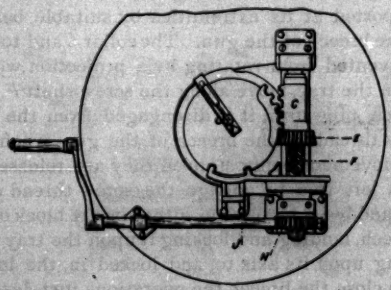


FIG. 3.

Canet-Whitworth breech-mechanism.

effective gas-checking and positive discharge of cartridge case when employing fixed ammunition. The lighter ones, although applicable to the heavier guns, are employed principally for rapid fire guns.

For calibres up to and including eight-inch, the breech plug is disengaged and withdrawn by a simple rotary single

movement of a lever in a horizontal direction and again entered and engaged by a similar movement in the reverse direction.

For the heavier guns, where hand power is employed instead of pneumatic or hydraulic power, the breech plug, carrier or tray and fittings are controlled, disengaged and withdrawn by a continuous rotation of a crank in one direction and the reverse movement governed by a similar rotation in the opposite direction.

The re-cocking is performed by levers and sliding bars during the operation of opening the breech and safety guards are automatically adjusted in the closing, which prevents any possibility of the gun being fired before the breech is perfectly closed. Spring catches are fitted to control the motion of the various parts while the breech is open.

In the Canet system when the shaft *J* (*Fig. 3*) is rotated, motion is communicated through a worm at its end to the worm-wheel *H*, which is fitted and gives motion to the screw-shaft *F* supported at its extremities by suitable bearings screwed to the breech of the gun. The collar *C* and toothed-wheel *E*, prevented from rotating by a projection working in a groove in the tray, move along the screw-shaft *F*, rotating the breech plug until it is disengaged from the interrupted screw threads in the breech of the gun, when their translatory movement being stopped they are released and the wheel is left free to engage the screw thread of the breech plug, and by its revolution withdraw the block or plug from the breech, landing and locking it upon the tray which is then swung upon its axis to, and locked in, the loading position. To close the breech the operations just described are reversed (*Fig. 2*). All of these operations are done by a continuous rotation in the direction requisite for opening or closing the breech.

The de Bange gas check* proper is a plastic ring composed of sixty-five per cent. of amianthus (an earth or mountain flax, similar to asbestos) and thirty-five per cent.

* Lantern view.

of tallow, contained in a canvas covering. It fits snugly around the mushroom-shaped stem which is inserted in the axis of the breech block. Zinc, copper or steel discs protect the plastic pad and keep it within its proper limits. The asbestos, being a mineral, and not combustible, retains the tallow and prevents the mixture from becoming fluid. The tallow

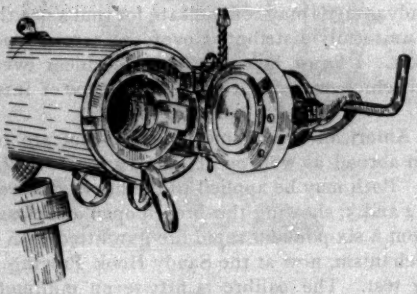


FIG. 4.

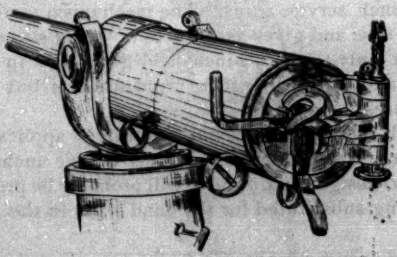


FIG. 5.

Seabury breech-mechanism.

being soft and greasy, yields easily to the pressure and takes the form of its casing; oozing slightly through the canvas cover it acts also as a lubricant.

When the gun is fired, the pressure upon the movable head is transmitted to the gas check, which is forced against the side of the chamber, effecting perfect obturation.

Although *not* the case in all constructions and particularly in the French, the breech screw or plug should engage in the jacket and not in the tube.

Canet suggests that the thread be interrupted by cutting away helical* segments instead of straight longitudinal ones, which is the usual method. This would make the mechanism not quite so simple to manufacture as the other, but its advantages may compensate for that since the thrust is more uniformly distributed over the screwed portion of the jacket. I know, however, of no accident ever having occurred which was due to the usual type of interrupted screw.

Two American breech mechanisms, that are receiving attention abroad as well as at home, are the Seabury and Gerdon. Both may be applied to the heavy calibres.

Figs. 4 and *5*, showing the breech open and closed, were taken from a six pounder rapid fire gun fitted with the Seabury mechanism, now at the Sandy Hook Proving Ground awaiting test. The calibre is fifty-seven millimetres, the same size as the Hotchkiss and Driggs-Schroeder two-and-one-fourth-inch service guns. The mechanism works with the utmost ease and gives assurances of being successfully applied not only to the 3·2-inch field guns, now in use in the Army, and to the four-inch rapid fire arm but to still larger calibres.

Although there is no necessary limit in its application to either large or small calibres, for guns of five inches and upwards, *this* design, *Figs. 6* and *7*, will probably be preferred, gearing being substituted for the hand lever in the largest sizes.

The Gerdon system of breech mechanism, *Figs. 8, 9* and *10*, is a combination of the interrupted screw with the sliding wedge, or a contrivance composed of what Mr. Gerdon considers the best elements of those two well-known and prolifically modified devices. He claims to reduce the three motions of rotation and translation of the French system to one of each retaining the superior de Bange gas check; but

* Lantern view.

as these three motions have been converted into a continuous one in the Canet and Seabury systems, the test of the Gerdon device that is now being made in a field gun may

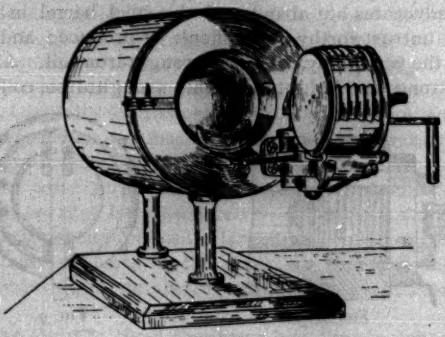


FIG. 6.

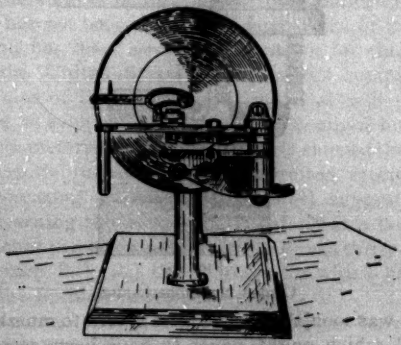


FIG. 7.

Seabury breech-mechanism.

not prove the combination to be as simple and effective as the latest designs of the French type.

A variety of materials has been proposed and advocated for heavy gun construction, but *steel* advocated by Whit-

worth and Krupp as early as 1860 and still employed by them has vanquished all others in the race and seems likely to be retained for as long a period to come.

Armstrong accepted steel and breech loading with other early advocates but abandoned the steel barrel in 1861 as being untrustworthy and difficult to produce; and substituted the very justly criticised wrought-iron coil. Although Armstrong was knighted for this wrought-iron coil breech

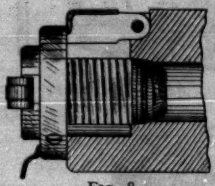


FIG. 8.

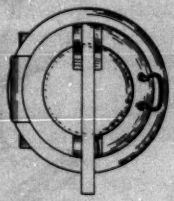


FIG. 9.

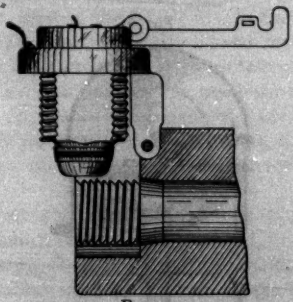


FIG. 10.

Gerdon breech-mechanism.

loader it was soon abandoned for a return to muzzle loading. The coil which ought never to have been accepted was retained while that feature which was a marked advance in artillery—breech loading—was abandoned.

Captain Eardley-Wilmot considers this was not a retrogade step at the time when guns were short and could be more conveniently loaded with simpler means, but thinks that England's fault was in returning to the system o

muzzle loading, to which she reverted, after the introduction of slow-burning powder which requires a long gun to utilize all its energy.

Whitworth and Krupp, however, stuck to steel and breech loading, and history has well endorsed and proved their foresight and judgment; and although Great Britain waited a quarter of a century before she acknowledged Whitworth's supremacy in gun-making, she has at last done so, and Mr. Gledhill's (Whitworth & Co.) type of gun and the material of which it is made stands in the front rank to-day.

Both branches of our Government use almost exclusively, for their *heavy* guns, fluid-compressed, hydraulic-forged, steel, and, as they have become assured of the soundness of the material when produced in larger masses, have decreased the number of parts of the guns; for example, those of the eight-inch gun, numbering ten in 1887, to three parts in 1892.

As the Midvale Steel Company has already delivered a considerable number of forgings for the smaller calibres of steel that has not been either fluid-compressed or hydraulic-forged, and has been awarded a contract for the heavier calibres, the United States Government's comparatively exclusive use of the water-shaped material will probably soon cease, as even as far back as 1884 comparisons of the physical characteristics of the two steels showed the uncompressed material fully equal to the required specifications.

The increasing use of nickel in steel suggests a few words concerning this element, particularly as it is about to make its debut in a large calibre service gun (a thirty-five calibre eight-inch B. L. R.), the forgings for which have been made by the Bethlehem Iron Company.

In this connection it is most seriously to be regretted that circumstances of a discouraging character should have intervened to prevent Mr. Riley from continuing the excellent metallurgical work he so happily and ably commenced in connection with the alloys of nickel and steel, for the reason that since the publication of his lecture to the Iron and Steel Institute, May 4, 1889, so many of his views have been proved by further experiment and practice.

Bethlehem's part in this work is so well known by the practical results she has obtained, the gun forgings and other products supplied and the superior resistance of her armor, that I need make no detailed statement here of our accomplishments. Further, they have already been referred to by the chiefs of the Bureaus of Steam Engineering and Ordnance in their last annual reports.

As you will no doubt recall, Riley, Dick and Packer commenced their experiments with samples of French crucible nickel steel containing three per cent., five per cent. and twenty-five per cent. of nickel; were subsequently assured by personal investigation that the desired products could be obtained with certainty, not only in the crucible but with perfect control in the open hearth, and that nearly all the nickel would be found in the steel. Riley, in the lecture referred to, described the action of the steel in the mould, its appearance, value of scrap and the care and temperatures required to work it. He made a sufficient number of tests to show the marked increase of tensile strength and elastic limit produced by certain increments of nickel without impairing the elongation or contraction of area to any noticeable extent. He pointed out the effects of a variation of the proportions of carbon and manganese with the same percentage of nickel, the point where the increment of nickel changed its hardening influence to one of softening ductilizing, its neutralizing effect upon carbon, the difficulties of machining, and crowned his report by giving due credit to the patentee, French steel makers, his assistants and the authorities.

Together with other conclusions, he said: "I am glad to be able to state that before the region of extreme difficulty of machining is reached we have qualities of nickel-steel available which will be of the utmost value for a very large number of purposes."

Comparing ordinary steel with nickel steel he adds: "I think there will be no hesitation in deciding that there will be a very great advantage gained by the use of the latter—advantage either in reduction of scantling or in increased strength and ductility.

"In the very important matter of corrodibility, it is with the greatest satisfaction I can state that the steels rich in nickel are practicably non-corrodible, and that those poor in nickel are much better than other steels in this respect. Some samples of the richer nickel-steels which have been lying exposed to the atmosphere for several weeks will show an untarnished fracture."

These experiments to test the non-corrodible qualities of the various percentages of nickel-steel, it will be remembered, were made in connection with Abel's corrosive liquid and hydrochloric acid water.

I have cited Riley's conclusions to show how accurately they have been verified by the results since obtained, which give abundant testimony of the care and faithfulness with which his experiments were made.

Mr. Hall, of Sheffield, claims to have made the first nickel-steel gun, which instrument is reported to have burst at the first round, the rupture being due to the absence of suitable transverse strength. Whether this was due to the poor steel, poor construction, or the presence of nickel was not stated.

Many other nickel-steel guns have been experimented with, but Krupp's comparative tests of two three-and-a-half-inch field guns, one made of ordinary Krupp steel, and the other of nickel steel, appear to be the first trials of much importance that have been given publicity.

Each gun was loaded with shell containing 170 grammes of picric acid, the centre of the shell in each case being 300 millimetres from the muzzle.

When the shells were exploded, the crucible steel gun burst into many pieces, while the nickel-steel gun remained entire, showing an increase of the bore of 7·4 millimetres at the site of the projectile, but no cracks anywhere.

The trial was continued with another shell containing 180 grammes of picric acid. Its explosion caused an enlargement of 9·50 millimetres and a longitudinal crack 80 millimetres long. No particle of metal was detached from the gun.

In reference to the suppy of nickel for guns, armor and

the great variety of the industrial arts, a perusal of the able report of Mr. Archibald Blue, Director of the Bureau of Mines, Ontario, will satisfy you all that the ore is to be found in abundance nearer than New Caledonia, money and plant being important requisites.

Mr. Blue has kindly sent me samples of the nickel ores of the various districts, but their delivery has been delayed by the same storm that has kept some of your members at home to-night.

I am also indebted to Mr. Robert M. Thompson and Lieutenant Cornwell, of the Orford Copper Company, of New York, for the samples before you of nickel matte and refined nickel.

In connection with gun construction, it may be interesting to you to recall some of the earlier breech-loading guns, in order that you may recognize the progress that has been made. The original Armstrong gun* contains practically nothing that has been retained, while the Whitworth gun* here shown, made in four parts, contains, with the exception of the mechanical shape of its bore, much that is in use to-day; it was made of steel, of few parts, and had great strength and high power. It is true it is a later design than the original Armstrong gun, but the earliest Whitworth guns were made of steel, were strong, and had a very efficient wedge* for closing the breech.

Passing from the Armstrong gun of 1861 to another of that famous establishment's productions thirty years later, we have before us the 110-ton breech-loading rifle* which, with 960 pounds of brown prismatic powder, costing $400, discharges a steel projectile weighing 1,800 pounds, valued at $600; muzzle velocity, 2,087 foot-seconds; muzzle energy, 54,390 foot-tons; penetration of wrought iron at muzzle, 34·2 inches, at 2,000 yards, 30·1 inches.

The British 110-ton guns, about which there has been so much discussion, are not only faulty in construction, but are composed of too many pieces, the chase hoops particularly being too numerous and short to be of any use in supplying

* Lantern view.

the longitudinal support which the long tube requires. The original design has undergone two marked changes, substituting longer hoops, but even these were not of sufficient proportions to entirely remedy the defects of the separation of the remaining short hoops on the upper side caused by the drooping of the muzzle.

The gun, even as it now exists, should not be imitated, and will not be by such gun factors as Whitworth and Bethlehem, who possess the powerful appliances requisite for shaping, treating and assembling the few heavy parts that should make up guns, even of such heavy calibres.

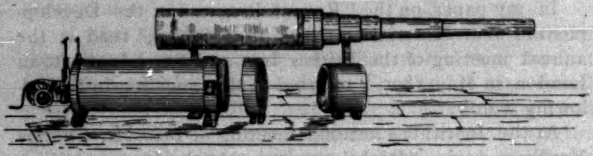


FIG. 11.

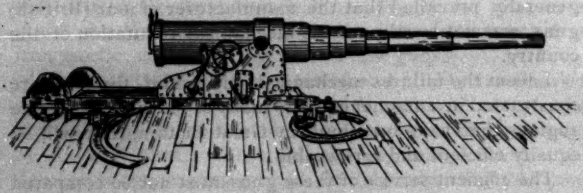


FIG. 12.
De Brynk B. L. rifle.

Whitworth's new thirty-five calibre twelve-inch, fifty-ton breech loaders for the British War Office, composed of three pieces only, are but a precursor of as simple and strong a design for the heavier calibres.

Another design, *Fig. 11*, combining few parts, simple construction, strength, separation of the transverse and longitudinal strains, in which the tube can be turned in case any portion of it becomes badly eroded, easily transported in parts, and readily taken apart if any injured parts require to be replaced, is the de Brynk gun, the suggestion of a

Russian artillery officer. A number of these guns have already been put into service.

Fig. 12 is the gun assembled.

I desire to especially emphasize the causes of the mishaps to the British 110½-ton guns, because their failure does not convey to my mind any reflection upon the usefulness of such large calibres, for it is quite as simple for the steel works I have just named to construct a sound 110-ton gun as it is for smaller establishments to make a one-pounder; and there can be no doubt that the more powerful the guns of a battleship are the more formidable an enemy she will be.

In my paper, on the "Recent Progress in the Development of War Material in the United States," read at the annual meeting of the British Iron and Steel Institute in London, in May, 1891, I referred to this question in the following words:

At the Institute's autumn meeting of 1886, Mr. Charles Markham said: "Rightly or wrongly the strong feeling generally prevailed that the manufacturer of our (British) guns was not worthy of the mechanical reputation of the country."

I deem the failures mechanical only, and if the guns are constructed in a manner equal to many of the modern marine engines that have been built in Great Britain, they will be equally efficient and serviceable.

The efficient service of these guns must not be compared directly with the number of rounds that can be fired from smaller calibres, and the weight of metal thus employed, but from the effective amount of destructive work that can be got out of them, particularly their power to demolish the hard armor of chilled iron and case-hardened steel now so successfully manufactured.

The United States is not the only nation engaged in successfully producing hard armor, nor is the method employed by Mr. Harvey, although thus far the most successful, the only one that the gun has to meet.

The general success and probable general acceptance for a period, of hard armor, would seem to emphasize the

opinion I have so often expressed that Great Britain's reduction of fifty per cent. in the maximum weight of her ordnance was too radical and not justified by the circumstances attending the failures that influenced the change.

The tendency to substitute for the larger armament an increased number of guns of reduced calibre, notably of the rapid-fire class, will no doubt soon meet with a reaction, because of the loss of that powerful element of destruction, the shattering power so necessary in combat with heavily armored ships. A mixed battery of large and small guns is no doubt the most useful compromise, for what is a ship to-day other than a compromise—in fact, a combination of compromises?

Of other systems of gun construction and other material than forged steel, recommended for trial within the last few years, may be mentioned the Woodbridge wire-wound guns* of ten-inch calibre (employing longitudinal bars and soldered wire) for the Army, and six-inch for the Navy; the Crozier ten-inch wire-wound gun (jacketed and hooped with steel castings); the five-inch Brown segmental tube wire gun;* the Haskell multicharge gun; the twelve-inch cast iron mortar, and two six-inch steel cast guns.

Three of these have been tested and failed, viz: the two steel cast guns and the twelve-inch cast-iron mortar. In December, 1888, the Bessemer steel cast gun went to pieces at the first round with a full charge, doing considerable damage to the proving ground. In February, 1889, the open-hearth steel gun was tested; the report of the trials stated that although the gun escaped rupture the test demonstrated, as calculated, that the service pressure, while less than fifteen tons to the square inch, was too great for the elastic limit of the metal and that the permanent enlargement of the bore was greater than could be admitted in a gun issued to service.

The twelve-inch cast-iron mortar* burst explosively and violently in October, 1889, at the twentieth round, and a long-fought battle for cast iron was finally decided.

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* Lantern view.

Some of you will recall that a gun of the Woodbridge type and one of the Haskell type failed a few years ago, and although slow-burning powder has in a much simpler way supplied what the Lyman-Haskell type was designed to accomplish, Congress authorized the construction of another gun which is now being built from designs possessing a little less architectural beauty than the one* now before you, but quite as unmechanical.

For mortars, the forged built-up rifled type of steel construction is also generally accepted and greatly increased accuracy and range are obtained.

Viewed from the point of their destructive power, if successful, the pneumatic and other types designed for throwing high explosives should be embraced in this paper, but they are not yet assigned a place among high-power breech-loading rifles, although many of them have been undergoing trial for years with varying success and failure.

Bott, Chamberlain, Dudley, Ericsson, Gathmann, Giffard, Graydon, Haskell, Justin, Lässoe, Mefford, Rapieff, Reynolds, Zalinski and others have had their inventions tested more or less extensively, employing air or powder for transmitting energy to the projectile. Bott and Chamberlain, I think, are the only ones who place the motive-power in the projectile itself. It is said that Bott fills the rear of his shell with compressed air instead of introducing the air in the gun; while Chamberlain uses electricity and hydrogen in either the projectile or gun. Giffard employs liquid carbonic acid instead of powder.

Of all these types, the Ericsson-Lässoe (submarine) and Rapieff-Zalinski, with its modifications (aërial) have given the greatest promise, and will, no doubt, be introduced into general service.

Rapid-fire guns have already gone beyond their own domain and encroached upon the field of heavy ordnance, having been successfully carried to calibres a little above six inches.

To fully describe the many designs for which novelty

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* Lantern view.

and value are claimed would require many days, and the differences between them would be of little interest to others than the inventors and patent attorneys.

In regard to the development of our industries for the supply of heavy ordnance a most satisfactory account can be rendered.

In 1886, we had practically nothing. To-day, steel for guns of any calibre can be supplied by the private steel industries of the nation, and two splendid gun factories have been built and equipped where the forgings can be quickly machined and assembled, and the guns rapidly fitted for service. These two gun factories will soon be supplemented by a third, at Bethlehem.

Not only all this has been accomplished, but from the great establishment at Bethlehem alone (built up and equipped without any financial aid from the Government), the Government has received over 300 sets of gun forgings (including those of thirteen-inch calibre) and armor-plates of ten and one-half-inch and fourteen-inch thickness, whose resistance has astonished the world; while the Navy Department and our splendid ship-yards depend almost solely upon it for shafting and other heavy forgings.

There are many to whom much credit is due for this splendid progress (and your Midvale deserves no small part of it), many spokes of the wheel that is running so smoothly and successfully now, but most credit seems due to the organization of and encouragement given by Secretaries Chandler and Lincoln to the Gun Foundry Board appointed by President Arthur in 1883. This Board, after familiarizing itself with the situation at home, gleaned from the old world all that was needed to frame recommendations adapted to our own resources and requirements. Its suggestions were so comprehensive that we find the policies of the two departments to-day encompassed by them.

This report and the subsequent legislation based thereon marked as distinct an era in the restoration of our prestige as producers of war material as the Registry Bill passed last year bids fair to record in the rehabilitation of our merchant marine.

To show the effect of modern steel projectiles, when fired at high velocities against steel plates, I have prepared the following views* of the results of the test of an eleven-and-one-half-inch Bethlehem plate.

These results, however, have been so greatly surpassed by succeeding experimental and service plates which Bethlehem has delivered to the Government, that they are presented only for the purpose of showing the value of our first production and to serve as a comparison for the greater resistance secured in our later plates. Without giving details of the many experimental and ballistic trials to which our armor has been subjected, I have cited one of a fourteen-inch nickel-steel plate,* representing battle-ship armor and that which took place at Bethlehem's Proving Ground,* July 30th last, when the ten-and-one-half-inch nickel-steel Harveyized plate so completely pulverized the five eight-inch, 250 pounds Holtzer shells fired at a striking velocity of 1,700 foot-seconds, and aggregating an energy of 25,040 foot-tons. Both plates were subjected to unusually severe tests; in fact, very much more severe than the foreign standards. Against the first a ten-inch gun was used, the projectile weighing 500 pounds, powder charge of 140 pounds, and a striking velocity of 1,410 feet a second. None of the three shots fired succeeded in getting far enough into the plate to show the backing. All three shots rebounded, one of them back to the muzzle. The deepest penetration was fourteen inches. One of the projectiles, an imported Firth, broke. The plate was perfectly uniform; there were no cracks and not even a bolt or washer started.

The results with the second,* although not comparable from the same point of view, were even more remarkable.

In the one case we have a type of resistance which will keep out a projectile of any calibre if thick enough, while in the other, a plate that will destroy the projectile until a calibre is reached whose smashing and racking energy will demolish the protection, although, perhaps, at the risk of its own destruction.

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* Lantern view.

In either case the heavy calibres will be needed.

Before closing, I desire to call your attention to this view* of the comparative sizes of the guns now used by our Navy with their projectiles and powder charges, commencing with the one-pounder and finishing with the sixteen-inch, 111½-ton gun.

All but the last have been made, and Bethlehem has had the honor of supplying steel for all the calibres up to and including the thirteen-inch.

This table* contains the details of all Navy guns commencing with the four-inch, and I will leave it before you for those who are not already familiar with its contents.

Mr. Chairman, it has given me great pleasure to accept your invitation this evening to talk with you upon a subject so closely connected with the development of our Navy.

The recent legislation, offering American registration two of the fastest transatlantic steamers, is but a small link in the chain needed to restore our supremacy of the seas; but, like the Irishman who, when he had secured a place for his head in Paradise, had no fear for the rest of his body, this is the link that will not long be left alone, and I am sure that I can safely predict a very near future when our flag will fly at the peaks of a merchant fleet which will advance our commercial interests in every part of the world, and be a menace to any nation that will be unwise enough to have any serious quarrel with us.

Mr. Chairman and gentlemen, I thank you for your kind attention and know you will all join me in thanking Mr. Sawyer, for his able assistance in presenting my illustrations.

NOTE.—Mr. Jaques' paper was elaborately illustrated by a large number of appropriate lantern views, which facilitated following the writer's text.

He exhibited a six-inch Holtzer armor-piercing shell which had been fired against Bethlehem's eleven-and-one-half-inch experimental plate; it was perfect; its point as sharp as a needle; and could be used again after re-banding.

Mr. Jaques also showed his hearers samples of nickel matte from the Sudbury Mines; of refined nickel from the Orford Copper Company; and of nickel-steel armor made by the Bethlehem Iron Company.

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* Lantern view.

THE SPECIFIC HEATS OF THE METALS.

BY JOS. W. RICHARDS, PH.D.,
Instructor in Metallurgy, etc., in Lehigh University.

[*A lecture delivered before the Franklin Institute, January 30, 1893.*]

[*Continued from p. 53.*]

V.

The heat or energy absorbed by a substance for 1° rise of temperature is divided up in the body into several parts. One fraction of it does external work, if the substance is free to expand. The amount of this for solids and liquids is so small as to be negligible, but for gases it amounts to as much as two-fifths of the whole specific heat. As far as the metals are concerned, we can neglect it. A second fraction of the energy absorbed goes to increasing the energy of atomic motion within the molecule. For solids and liquids, where the molecule is complex, this will amount to a considerable proportion of the whole; for gases it is a much smaller fraction. The third and last part of the energy absorbed may be considered as going to increase the energy of vibration of the molecules as a whole; that is, increasing the temperature of the substance; for, on the mechanical theory of heat, the temperature of a body is measured by the energy of vibration of its molecules as a whole. We can therefore put

$$Q = \text{molecular energy} + \text{atomic energy} + \text{external work}.$$

Leaving out of the discussion the last term, we may say that the proportion which the first two terms bear to each other or to the whole has not been solved for solid and liquid bodies, but has been worked out very satisfactorily for gases, especially by Clausius and Naumann.

The most striking law which has been discovered regard-

ing specific heats is the law of Dulong and Petit, which affirms that they vary inversely as the atomic weights of the elements. The metals behave very well in this respect, the products of their atomic weights and specific heats being all nearly the same. But, in order to attain this uniformity, the metals must be compared at ordinary temperatures, since the specific heats vary so greatly. Iron, for instance, gives the usual product, about 6·3, if the specific heat at 50° is taken, but if its specific heat at 900° were taken this product would be just about double. But, the fact remains that there are slight variations in the products (atomic heats) at ordinary temperatures, and much speculation has been indulged in regarding their causes. In some instances, a great variation has been due to incorrect determinations of the specific heat, or from the specimen used not being perfectly pure. Manganese, for instance, has never been obtained perfectly free from silicon or carbon, either of which increases its specific heat; while aluminum has generally been used containing iron, which decreases its specific heat. Determinations with the chemically pure metal would give in both cases atomic heats nearer the average. Yet, allowing for this source of error, there are still variations to be explained, and the only reasons we can assign are that the metals are in different states of aggregation, requiring different amounts of work to overcome the interior cohesion of the particles or to elongate the metal. It is possible, therefore, that the differing densities, hardness and strength of the metals are the various disturbing influences which prevent their atomic heats from being exactly alike at ordinary temperatures.

Some investigators have tried to bring these facts into the calculation and take strict account of them. P. Joubin, for instance, states that for any metal the product of the specific heat and specific gravity (which would be the specific heat of unit volume) is proportional to the product of the modulus of elasticity into the [linear (?)] coëfficient of expansion by heat. H. Fritz states that the product of the atomic heat, the specific heat of unit volume and the cube root of the atomic volume is equal to the cube root

of the absolute temperature of the melting point into the specific heat of unit volume divided by 1·28; that is,

$$(\text{at. ht.}) \times (\text{sp. ht. unit vol.}) \times (\text{at. vol.})^{\frac{1}{3}}$$

$$= \left[\text{M. P.} \left(\frac{\text{sp. ht. unit vol}}{1{\cdot}28}\right)\right]^{\frac{1}{3}}$$

Fritz claims to have verified this formula for forty-eight of the elements, but I cannot offer any remarks, not having seen the original paper.

Weibe holds that the amount of heat necessary to raise an element from the absolute zero to its melting point (taking atomic weights) is inversely apportioned to its coëfficient of cubical expansion. This rule holds good for some of the elements, especially for those crystallizing in the isometric system, but there are many exceptions to it, so that is not a satisfactory solution of the problem of reconciling the differences in the atomic heats.

A rule of somewhat similar nature has been discovered by the writer, applying to the latent heats of fusion. I have found that the latent heat of fusion of the metals is frequently a simple fraction of the heat required to raise the metal from the absolute zero to its melting point. It is in many cases simply one-third. Let us illustrate by several examples, referring to the previous discussions for the data:

Tin:

	Calories.
Bède's formulæ would give for the heat from absolute zero to melting point,	27·6
One-half of this would be,	13·8
Observed by Person,	13·73
Observed by Richards,	14·56

Silver:

Pionchon gives from M. P. to 0°,	60·32
Formula suggested gives (0° to 273°),	14·45
Total heat to absolute zero,	74·77
One-third of this,	24·92
Observed by Pionchon,	24·72

Platinum :

	Calories.
Gives in cooling to 0° (Violle),	75·21
From 0° to — 273° (Violle's formula),	8·19
Total to absolute zero,	83·40
One-third of this,	27·80
Observed by Pionchon,	27·18

Cadmium :

Naccari's formula gives the mean specific heat to absolute zero 0·05, from which the total heat would be,	29·70
One-half of this,	14·85
Obtained by Person,	13·66

Zinc :

Le Verrier gives as the heat to 0°,	46·9
Formula (Bède's) gives from 0° to 273°,	24·3
Total heat to absolute zero,	71·2
One-third of this is,	23·7
Obtained by Person (corrected),	22·6

Bismuth :

Taking Bède's formula, and correcting it so that it passes through Regnault's value, we get the equation

$$Q = 0{\cdot}0308\, t + 0{\cdot}00002\, t^2$$

which gives for — 273 to + 266·8,	16·57
One-half of this would be,	8·28
Obtained by Person (corrected),	8·88

Copper :

The formula worked out by the writer gives from — 273° to 1,054°,	143·
One-third of this is,	47·7
Observed,	43·3

Palladium :

Gives out to 0° (Violle),	109·8
From — 273° to 0° (Violle's formula),	15·1
Total to absolute zero,	124·9
One-third of this is,	41·6
Obtained by Violle,	36·3

(Violle remarks that this was an experiment of unusual difficulty, and that the result is approximate.)

Mercury:

	Calories.
Taking Regnault's value for the specific heat of solid mercury, we have for the total heat from absolute zero to — 40°,	7·46
One-third of this,	2·49
Obtained by Person,	2·84

Alloys:

The rule applies probably to alloys also, for instance, *d'Arcet's Fusible Alloy*. Its specific heat at 30° is 0·062 (Spring). The mean between 96° and — 273 is very probably smaller than this, but how much we cannot say, probably ten per cent. However, the above value would give for the heat from absolute zero,	22·88
One-third of this is,	7·63
Observed by Person,	5·96

With metals having a small latent heat of fusion, the inaccuracies of the formulæ for the specific heat may introduce relatively large errors. After all, there are too many deviations and variations to enable us to claim any strict rule regarding these coincidences. All that I wish to do is to call attention to the fact that for bismuth, cadmium and tin the latent heat of fusion is very nearly one-half the total heat in the solid metal at its melting point, while for silver, platinum, zinc, copper, palladium, mercury and d'Arcet's alloy it is close to one-third. The latent heat of fusion of silver may be assumed as probably the most accurate known, as also the curve of its specific heat, and in this very case the proximity of the ratio to one-third is the closest.

I might close by venturing a prediction. The best results we have for *gold* would indicate about forty-two calories as the amount of heat contained in the solid metal at the melting point. If the ratio in this case is one-third, as its similarity to silver, copper and platinum might indicate, its latent heat of fusion would be about fourteen calories. It has not yet been determined, to my knowledge.

APPENDIX.

ALUMINUM.

[See a *résumé* on this subject by J. W. Richards, in this *Journal*, February, 1892.]

First investigated by Regnault, in 1855, on very impure metal, obtaining 0·2056 between 25° and 97°, and allowing for the impurities present, he made the figure for pure aluminum 0·2181. Had he used the correct specific heat of silicon in making this allowance, he would have obtained 0·2200.

Investigated again by Regnault, a year after, on purer metal, obtaining a corrected value of 0·2143 (14°–97°).

Kopp used ordinary commercial aluminum, and obtained 0·2020 (20°–52°), as the mean of four determinations which varied from 0·1970 to 0·2070. This determination is, therefore, of very little value.

Mallet used chemically pure aluminum, and found by the Bunsen calorimeter 0·2253 (0°–100°).

Naccari (purity of metal not stated) investigated up to 300°, by the method of mixtures. His results lead to the formulæ:

$$S = 0{\cdot}2116 + 0{\cdot}000095\, t$$

$$Sm = 0{\cdot}2116 + 0{\cdot}0000475\, (t + t')$$

The mean 0°–100° would be 0·2164.

Richards used metal which analyzed 99·93 per cent. aluminum, the rest silicon. Temperatures pushed to 600°. Formulæ arrived at:

$$S = 0{\cdot}2220 + 0{\cdot}0001\, t$$

$$Q = 0{\cdot}2220\, t + 0{\cdot}00005\, t^2$$

Mean 0°–100°, 0·2270, being less than one per cent. from Mallet's value. The rate of increase with the temperature is similar to Naccari's observation. Total heat contained in the solid metal to its melting point (625°), by this formula, 158·3 calories.

LeVerrier finds the specific heat between 0° and 300° to be invariable, and = 0·22; between 300° and 530° also con-

stantly = 0·30; between 530° and 560° an absorption of about 10 calories rendered latent; between 540° and 600° the specific heat again constant and equal to 0·46. For the total quantities of heat in the metal, he gives the following formulæ:

$$\text{Between } 0° \text{ and } 300° \quad Q = 0{\cdot}22\, t$$

$$300° \text{ " } 530° \quad Q = 65 + 30{\cdot}0\,(t - 300)$$

$$540° \text{ " } 600° \quad Q = 139 + 0{\cdot}46\,(t - 530)$$

Q becomes about 170 calories towards 600°, and rises rapidly passing 200 before fusion at 620°.

Pionchon has recently published the following results:

$$\text{Between } 0° \text{ and } 580° - Q = 0{\cdot}393\, t - \frac{291{\cdot}86\, t}{1517{\cdot}8 + t}$$

$$625° \text{ " } 800° - Q = 0{\cdot}308\, t - 46{\cdot}9$$

Specific heat at 0° = 0·2010; in the liquid state, above 625°, constant and equal to 0·308. He states that beginning at 580° the fusion starts, the metal losing its solidity, and between 623° and 628° the heat curve Q is nearly vertical. Pionchon's first formula gives for the total heat in the solid metal at the melting point 160·49 calories.

Latent Heat of Fusion.—In 1890, the writer determined the amount of heat in solid aluminum as near as possible to its melting point as 199·5 calories, and the heat in the molten metal as 229, from which he concluded that the latent heat of fusion was close to thirty calories. Since then, two sources of errors have been disclosed in this determination.

(1) The metal above 600° absorbs in advance some of its latent heat of fusion, the writer's observation in this regard agreeing with Le Verrier's, who states that the total heat exceeds 200 calories before real fusion occurs. If this phenomenon did not occur, the writer's formula would give the heat content at the melting point as 158·3, while Pionchon's formula gives 160·49, and it is these numbers which must be used in calculating the total heat absorbed during the change of state.

(2) The heat in the molten metal at its setting point is

very greatly modified by impurities present. The writer found the following heats in impure and pure metal:

Per Cent. Pure.	*Calories.*
96·9	229·0
99·9	254·0
99·93	258·3

The writer's results must then be considerably modified, in order to get the total latent heat. For the metal of greatest purity, the total calculated absorption between 600° and 625°, due to change of state, would be 258·3 — 158·3 = 100 calories. Pionchon's formula for the heat in liquid aluminum evaluated for the melting point gives 239·4 calories, and subtracting his lower value of 160·49, there is left 78·91 units as the latent heat. The writer's experiments would show that Pionchon's upper figure, 239·4, is probably nearly twenty units too low, since four experiments have given me 258·2, 258·9, 259·3 and 259·2, respectively.

ANTIMONY.

Professor Wilcke gave 0·063; Crawford, 0·0645; Kirwan, 0·086.

Dulong and Petit give 0·0507 (0°–100°) and 0·0549 (0°–300°), or in formulæ

$$S = 0{\cdot}0486 + {\cdot}000042\, t$$

$$Q = 0{\cdot}0486\, t + {\cdot}000021\, t^2$$

F. E. Neumann, using commercial metal, found its specific heat by the method of cooling as 0·0470.

Regnault:

0·05077. (61°–97°)

Bède gives the formulæ:

$$S = 0{\cdot}0466 + {\cdot}000040\, t$$

$$Q = 0{\cdot}0466\, t + {\cdot}000020\, t^2$$

Kopp gives:

0·0523 at 31° (unreliable)

Bunsen:

0·0495 at (0°–100°)

L. Pebal and H. Jahn found the following mean values:

$$Sm\ (-21^\circ \text{ to } -76^\circ) = 0{\cdot}0496$$

$$Sm\ (-21^\circ \text{ to } -\ 0^\circ) = 0{\cdot}0486$$

$$Sm\ (\ 0^\circ \text{ to } -33^\circ) = 0{\cdot}0495$$

Naccari derives the formulæ:

$$S = 0{\cdot}04864 + {\cdot}0000167\ t$$

$$Q = 0{\cdot}04864\ t + {\cdot}0000084\ t^2$$

BERYLLIUM.

Emerson Reynolds found 0·642 (20°–100°); while Nilson and Pettersson obtained 0·408 (0°–100°).

T. S. Humpidge investigated carefully through a range of temperatures and gives the formula:

$$S = 0{\cdot}3756 + 0{\cdot}00106\ t - 0{\cdot}00000114\ t^2$$

This formula evaluated for (0°–100°) would give 0·4248. It is therefore probable that Reynolds' value is much too high.

BARIUM.

The Russian chemist, Mendeléeff, gives 0·05.

BISMUTH.

Professor Wilcke made its specific heat 0·043.

Dulong and Petit found 0·0288, and Neumann 0·027 by the method of cooling.

Regnault made it 0·03084 (14°–99°).

Bède made experiments up to 200°, from which he calculated the formula

$$Sm = 0{\cdot}0269 + 0{\cdot}00002\ t$$

which would give for (14°–99°) 0·0292, about five per cent. lower than Regnault's result.

Kopp found 0·0305 (12°–60°), close to Regnault's figure.

Person found the specific heat of molten bismuth between 280° and 360° to be 0·0363.

Latent Heat of Fusion.—Dr. Irvine, Jr., determined that the

latent heat would raise the temperature of 550 parts of solid bismuth 1° F., equal to 305·5 parts 1° C. He then assumed Wilcke's figure for the specific heat of bismuth, which gives its latent heat as 11·92 calories. Had he used the specific heat found since by Regnault, his experiments would give 10·3. Or, had he used the specific heat at the melting point as determined by Bède's formula, he would have obtained 10·8 calories.

Person made experiments with molten bismuth, from which he calculated that at its melting point (266°·8) it contained 94·88 calories. But, assuming Regnault's value to be true to the melting point for solid bismuth, the heat in solid bismuth is 82·24 calories, from which the latent heat of fusion is 12·64 calories. If, however, we take Bède's determination of its increasing 0·00002 for every degree rise in temperature, the mean specific heat to the melting point would be 0·0322, the heat in solid bismuth at its melting point 86·00 calories, and the latent heat of fusion 8·88.

CADMIUM.

Regnault found 0·0567 (16°–98°) on metal containing one per cent. of impurities.

De la Rive and Marcet found 0·0576, at ordinary temperatures, by the method of cooling.

Kopp found 0·0542 (15°–60°) method of mixtures.

Bunsen found 0·0548 (0°–100°) by the ice calorimeter.

Naccari experimented up to 300°, and gives the following formula:

$$Sm = 0{\cdot}0546 + 0{\cdot}000012\,t$$

This evaluated for Regnault's range of temperature gives 0·0560.

Latent Heat of Fusion.—Person found 31·83 calories in molten cadmium at the melting point (320°·7), and subtracting the heat in solid cadmium at that point, using Regnault's value, the latent heat of fusion became 31·83 — 18·17 = 13·66. Had he used Naccari's formula for the heat in solid cadmium he would have obtained 18·7, and for the latent heat of fusion 13·13.

CALCIUM.

Bunsen found 0·1722 and 0·1686, mean 0·1703 (0°–100°), by the ice calorimeter.

CERIUM.

Dr. W. F. Hillebrand gives 0·0448, at ordinary temperatures, determined on metal 95 per cent. pure, allowing for the impurities which were mostly iron and didymium.

CHROMIUM.

Kopp found 0·1000 (15°–60°); but since he found that of iron, with a larger atomic weight, to be greater than this, he concluded that this number must be too small, and supposed it due to the impurity of the material he was working with.

COBALT.

Dulong and Petit found 0·1498, by the method of cooling.

Regnault gives 0·10696 (13°–99°).

De la Rive and Marcet obtained 0·1172 as the mean of three experiments by the method of cooling. Regnault observes, however, that specimens containing carbon gave him as high as 0·117, but he took the smallest value as belonging to the purest metal.

Pionchon investigated up to 1,160°. He found the specific heat at 0° to be 0·10584, his formula up to 900° being

$$Sm = 0{\cdot}10584 + 0{\cdot}000022287\ t + 0{\cdot}0000000219427\ t^2$$

This formula evaluated for Regnault's range gives Sm (13°–99°) = 0·1086, about 1·5 per cent. higher than Regnault's value. At about 900°, however, Pionchon observed a sudden change in the specific heat, so that above 900° the mean specific heat to 0° is expressed by the formula:

$$Sm = 0{\cdot}124 + 0{\cdot}00004\ t - \frac{14{\cdot}8}{t}$$

He could not definitely determine just how much heat was rendered latent in this change at 900°.

COPPER.

Wilcke found 0·114; Dr. Crawford, 0·1111; and Dalton gave 0·11, the latter by the method of cooling.

Dulong and Petit found 0·0949 (0°–100°) and 0·1013 (0°–300°), from which follows the formula:

$$Sm = 0{\cdot}0917 + 0{\cdot}000032\,t$$

Regnault gives 0·09515 (17°–98°); Dulong and Petit's formula evaluated for this range gives 0·09535.

Bède obtained a considerably lower result, giving up to 250°.

$$Sm = 0{\cdot}0910 + 0{\cdot}000023\,t$$

which gives values at (15°–100°) about two per cent. lower than Regnault.

Kopp obtained values between 0·0895 and 0·0949, average 0·0925 (15°–60°).

Naccari worked up to 325°, and gives the formula:

$$Sm = 0{\cdot}0921 + 0{\cdot}0000106\,t$$

which gives at 17°–98°, 0·0933. This result is almost the same as Bède's, but for higher temperatures would be much below his.

Le Verrier says that the specific heat of copper does not increase regularly with the temperature, but is constant between certain limits, that is:

Between	0°	and 360°, ...	0·104
	360°	" 580°, ...	0·125
	580°	" 780°, ...	0·090
	780°	" 1,000°, ...	0·118

Further, that at the points where the changes occur there is heat rendered latent, about two calories towards 350°, two calories towards 580°, 3·5 calories towards 780°. He states that the total heat in the copper is 117 calories towards 1,020°.

In connection with Prof. B. W. Frazier, the writer has made a particular study of copper, reaching the conclusion that none of the above critical points occur, and that the specific heat increases regularly with the temperature according to the equations

$$S = 0{\cdot}0939 + 0{\cdot}00003556\,t$$

$$Sm = 0{\cdot}0939 + 0{\cdot}00001778\,t$$

$$Q = 0{\cdot}0939\,t + 0{\cdot}00001778\,t^2$$

These formulæ were the true expressions of the results obtained up to 900°, and at none of the temperatures designated as critical points by Le Verrier were any deviations noticed. It would have been impossible for an absorption of 0·5 calorie to have occurred without having been detected. The ratio of the specific heat of copper to that of platinum throughout this range did not vary one-half of one per cent. from 2·96, showing that the *ratio* of increase of specific heat with the temperature is the same in both metals.

Latent Heat of Fusion.—The mean value of six experiments on the amount of heat in molten copper at the melting point have given us 162·0 calories. The above formula evaluated for 1,054° gives for the solid copper 118·7 calories. We have therefore determined the latent heat of fusion as 43·3 calories.

DIDYMIUM.

Hillebrand obtained 0·04563 (0°–100°) in the ice calorimeter, allowing for 0·4 per cent. of silicon, 0·3 per cent. of iron and 0·1 per cent. of aluminum which were in the specimen.

GALLIUM.

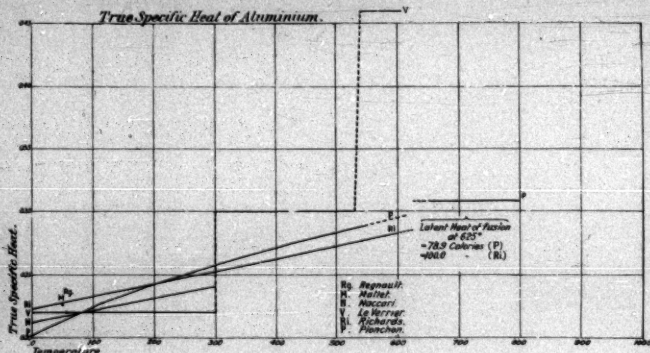
Bettendorf obtained 0·079 (12°–23°), for solid gallium. Tomassi (*D'Electrochimie*, p. 226), gives the specific heat of liquid gallium as 0·0802, and the latent heat of fusion as nineteen calories. I do not know the name of the investigator who determined these.

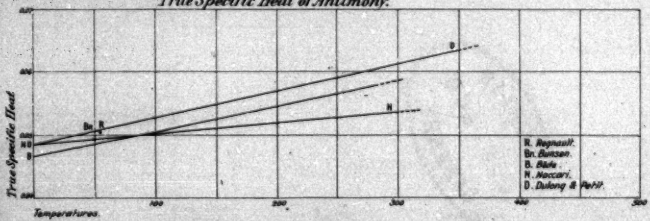
GERMANIUM.

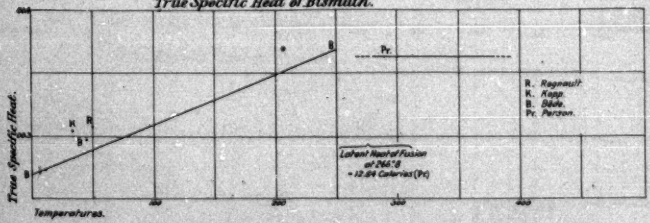
Nilson and Pettersson found the following mean specific heats:

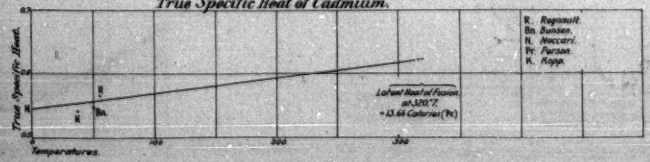
0° to 100°,	0·0737
0° to 211°,	0·0773
0° to 302°,	0·0768
0° to 440°,	0·0757

As there is evidently first an increase and then a decrease, no simple formula can be derived to express these results.


True Specific Heat of Aluminium.
True Specific Heat.
Temperature.
Latent Heat of Fusion at 625° = 78.9 Calories (P) = 100.0 (Ri.)
Rg. Regnault.
M. Mallet.
B. Naccari.
V. Le Verrier.
Ri. Richards.
P. Pionchon.


True Specific Heat of Antimony.
True Specific Heat
Temperatures.
R. Regnault.
Bn. Bunsen.
B. Bède.
N. Naccari.
D. Dulong & Petit.


True Specific Heat of Bismuth.
True Specific Heat.
Temperatures.
Latent Heat of Fusion at 266°.8 = 12.94 Calories (Pr.)
R. Regnault.
K. Kopp.
B. Bède.
Pr. Person.


True Specific Heat of Cadmium.
True Specific Heat.
Temperatures.
Latent Heat of Fusion at 320°.7 = 13.66 Calories (Pr.)
R. Regnault.
Bn. Bunsen.
N. Naccari.
Pr. Person.
K. Kopp.

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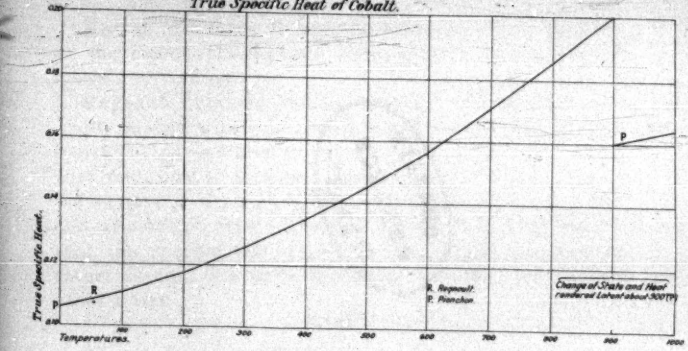
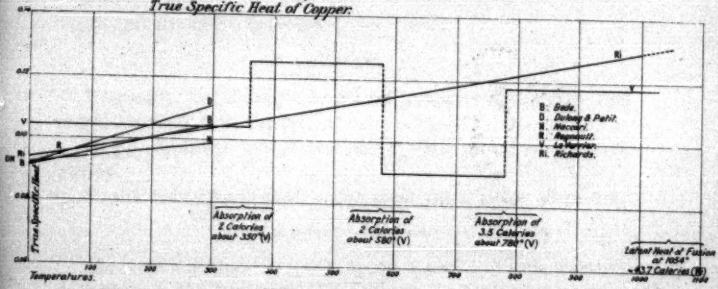
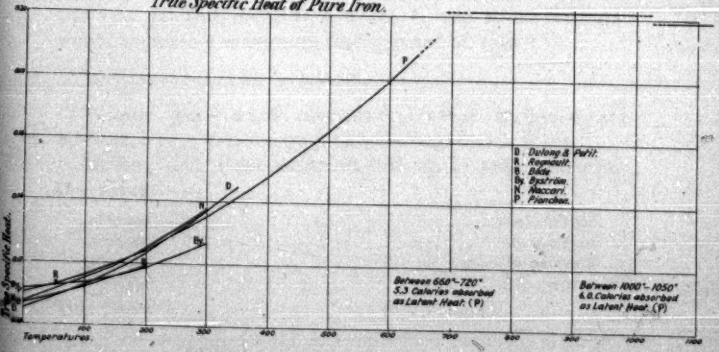
True Specific Heat of Cobalt.



True Specific Heat of Copper.


True Specific Heat.
Temperatures.
B. Bede.
D. Dulong & Petit.
M. Maccari.
R. Regnault.
V. Le Verrier.
Ri. Richards.
Absorption of 2 Calories about 330° (V)
Absorption of 2 Calories about 580° (V)
Absorption of 3.5 Calories about 780° (V)
Latent Heat of Fusion at 1054° = 43.7 Calories (R)

True Specific Heat of Pure Iron.



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GOLD.

Kirwan first made its specific heat 0·05; Dalton gave it as the same; Dulong and Petit obtained 0·0298 by the method of cooling.

Regnault obtained 0·03244 (12°–98°), with gold 999 fine. Violle worked with gold 1,000 fine, and obtained for 0°–100° 0·0316. This is stated to remain sensibly constant up to 600°, and then to increase gradually towards the melting point (1,035°). At 900°, Violle makes its specific heat 0·0345 and at 1,020°, 0·0352. It would appear from these figures that the specific heat of gold is more nearly constant, or rather changes less with the temperature than that of any other metal.

INDIUM.

Bunsen has found with the ice calorimeter 0·0574 and 0·0565, mean 0·0570 between 0° and 100°.

IRIDIUM.

Regnault found 0·03672 (17°–98°), but remarks that the metal he used was impure.

Kopp obtained 0·0358 (15°–60°), with metal of greater purity.

Violle found for it exactly the same value as for platinum,

$$Sm = 0{\cdot}0317 + 0{\cdot}000006\,t$$

He verified this formula up to 1,400°. Violle further determined the heat in solid iridium just set as 84·2, 85·3 and 83·9 calories, mean 84·5, which, by the above formula, would indicate a maximum fusing point of 1,950°.

IRON.

Wilcke gave 0·126; Crawford, 0·1269; Irvine, 0·143; Kirwan, 0·125; Dalton, 0·13, and Dulong, 0·11.

Dulong and Petit experimented up to 350°, obtaining the values

0° to 100°,	$Sm = 0{\cdot}1098$
0° to 200°,	$Sm = 0{\cdot}1150$
0° to 300°,	$Sm = 0{\cdot}1218$
0° to 350°,	$Sm = 0\,1255$

which would lead to the formulæ

$$Sm = 0{\cdot}1062 + 0{\cdot}000028\ t + 0{\cdot}00000008\ t^2$$

$$S = 0{\cdot}1062 + 0{\cdot}000056\ t + 0{\cdot}00000024\ t^2$$

It may be here remarked that all later investigators have reached similar formulæ of three terms, which means that the specific heat of iron increases more rapidly than the first power of the temperature. It should be borne in mind that these formulæ were verified only to 350°.

Regnault found 0·11352 (19°–98°), and after the same piece had been heated to redness 0·11380.

Bède obtained the following results:

15° to 100°, ...	0·11230
16° to 142°, ...	0·11533
20° to 247°, ...	0·12331

From these observations, he deduces the formula

$$Sm = 0{\cdot}1053 + 0{\cdot}000071\ t$$

but it can be seen from the data obtained that the value for 247° was higher than it should have been if the rate of increase had remained constant. A formula of three terms should, therefore, have been derived to fit the data, and he should have given

$$Sm = 0{\cdot}1050 + 0{\cdot}000065\ t + 0{\cdot}00000018\ t^2$$

It will be observed that the coëfficient of t^2 is smaller than in Dulong and Petit's formula, showing the curve to be nearer to a straight line.

Byström gives the true specific heat of iron, as deduced from his experiments, at every 50° up to 300°, as follows:

		Differences.
0°, ...	$S = 0{\cdot}111641$	
		0·000728
50°, ...	0·112369	
		0·001426
100°, ...	0·113795	
		0·002154
150°, ...	0·115949	
		0·002872
200°, ...	0·118821	
		0·003590
250°, ...	0·122411	
		0·004308
300°, ...	0·126719	

These data would lead to the formulæ

$$S = 0.11164 + 0.00000718\,t + 0.0000001436\,t^2$$

$$Sm = 0.11164 + 0.00000359\,t + 0.0000000479\,t^2$$

This formula differs from the previous ones in having a much larger value of the constant, a much smaller coëfficient of t and a larger coëfficient of t^2, which is shown on the diagram by the curve starting higher, being quite flat for a distance and then rising rapidly. This formula evaluated for Regnault's range gives Sm (19°–98°) 0.1127, about 0.75 per cent. below Regnault's value.

[*To be continued.*]

Notes on Ancient Temple Architecture.

By John M. Hartman.

[*Abstract of remarks made at the stated meeting, held April 19, 1893.*]

The Pyramids.—Herodotus tells us the stones were elevated with a machine made of short pieces of timber. This description answers to the tilting process, and that they blocked up after each tilt: a slow but sure method. By the same process the blocks could be taken sideways to their destination. The inclined gallery leading up to the King's Chamber has a ledge of stone projecting out about 24 x 40 inches high on each side. In the top of this projection are holes at regular intervals, evidently chock holes to block up after the granite blocks of the chamber and for taking up the sarcophagus. The Sphinx is carved from rock left in position when excavating for a place to set the pyramids. The stratification of the rock shows across the body and face.

Luxor.—At the temple of Luxor they have recently uncovered, at the bottom of the grand colonnade, a carving, showing a horseman following a chariot, which is the only instance of the picturing of a horseman in all Egyptian hieroglyphic writing. The two obelisks of this place (one of which is now in Paris) are the finest in the world, and

the carving, after 3,300 years, is as sharp and well defined as when made. They are of gray granite, highly polished.

The temple of Medinet Habu has sandstone girders, 24 x 30 inches and 15 feet long from column to column. The underside of these girders has fallen out in the form of an ellipse, showing the effort of nature in long ages to rid herself of surplus material. The remaining part has not broken in two, but forms an elliptic arch.

The Tombs of the Kings are long tunnels, driven in on a stratum of argillaceous schist. As the strata are somewhat distorted, the floor of the tunnel was driven to keep in this schist, as the adjoining rock could not be used; hence, the irregularities of the floor. This argillaceous schist, being very porous, has absorbed a large quantity of the paint employed in the pictures with which the walls are decorated, a fact which accounts for the almost perfect retention of the color after 3,300 years.

The pink granite (syenite) statue of Rameses the Great, sitting on his royal chair, was destroyed with fire and water by Cambyses, who could not break it in any other way. The broken statue now lies on its face. It is 21 feet across shoulders and originally was 60 feet high and weighed 850 tons. It is a perfect piece of Egyptian sculpture and brightly polished. This was the masterpiece of the old world, and nothing like it has been attempted since.

Edfou.—Some of the sandstone columns of this temple are enamelled in white. This enamel is so firmly laid on that it cannot be separated by breaking.

Philæ.—Into the walls of the temple of Philæ is built a large boulder, which has been surfaced off and on this the deed of presentation of the island to the priests of Isis, by Ptolemy II, was inscribed. The temple is in ruins, but the deed is perfectly preserved.

Syenite Quarries at Assouan.—The only place in the East where syenite, or pink granite, is found in quantity is at Assouan, and from this quarry came the columns of the Greek and Roman temples at Constantinople, Rome and Baalbec. To get the proper idea of the size of this quarry, which has been drawn upon for material by all ages,

it is best to ascend to its highest point, and to bear in mind that the sands of the desert have covered its greater portion in later years. Near the top of the quarry is an opening containing a monolith 12 feet square and 100 feet long, detached and raised up, but not removed. In the long after years from the time it was detached, the attempt has been made to break the monolith in two by cutting a groove around it, but the brains and hands of the masters who detached and raised it were not there and the trial of simply breaking it was a failure. The quarrying of one of these monoliths was a work of time. The top of the quarry having been dressed off, the outline of the monolith was laid off. Around this outline a channel about two feet wide was chiselled and broken out to the depth of the monolith. This channel was cut with a gouge or half-round chisel, about half an inch wide. A groove six inches deep was cut on each side of the channel and the granite broken out between the two grooves. The chisel marks left on the side face of the quarry vary, but are about six inches high or deep. Some of the cuts are perfectly uniform, showing the good workman; while others are irregular, showing the apprentice's hand.

After the first cut was started a second workman started in behind the first and took another six-inch cut; this process was followed by others until the bottom of the monolith was reached. All around the bottom of the block, square taper openings, 3 inches apart, about 3½ inches high by 5 inches wide, were cut wedge-shaped about 6 inches inward, after which each hole was wedged and the monolith split off. These taper holes with their sharp square corners are a marvel. Any mechanic trying to cut a square hole through a piece of cold iron with a hammer and chisel will appreciate what it means to make these openings after he has broken some of his chisels. From the fact that the monoliths left in the quarries lie at an angle, it would appear as if they had resorted to tilting and blocking to elevate them. In the limestone quarries they took a cut about twelve inches deep, and much coarser, as the material, being softer, permitted the use of a longer chisel, or gouge;

but with this hard, tough syenite, they had to use shorter chisels and take finer cuts. There is nothing in Egypt to prove the use of copper tools in stone-work, but they undoubtedly had good steel tools. The conquerors who succeeded the Egyptians, having nothing but fanaticism and insolence for their portion, could not make a pound of iron or steel, and from that day to this have been destroying the works of the old masters, to rob them of the iron used in their construction. The result is that even the tools of the ancient workmen have disappeared.

In Egypt all work is done sitting down. They turn table legs and all other wood-work on a lathe on the ground. The work is revolved back and forth by a large bow, worked with the right hand, the gouge or chisel cutting only when the work revolves forward. The left hand guides the outer end of the gouge or chisel, while the inner end is held to the steady rest between the first and second toe of the right foot. The first and second toe of an old turner lengthens out beyond the other toes, and the space between them increases. They grow like the thumb and first finger, as they gradually assume their new functions.

Jerusalem.—Jerusalem was originally a Phœnician town and summer resort from the heat of the lowlands. Good masonry with large blocks is found in the town wall which the founders built. When Solomon built his temple, he hired skilled workmen of Hiram, King of Tyre, a Phœnician city, to erect the masonry. Part of the temple was built on rocks levelled off, and where the hill sloped off, piers were carried up and arches sprung across them to get sufficient area for the temple. These piers contain blocks 30 inches square, 32 feet long, and are as good to-day as when built. Solomon used much wood in the temple, and when it was destroyed by fire, the arches, being of limestone, were calcined and ruined. When the Jews built the second temple they rebuilt the arches on the old piers. The second temple was smaller than the first, and when that was burned the arches were again destroyed, though only partly. Subsequently the Romans rebuilt the arches and temple, which accounts for the three different styles of masonry, concern-

ing which there has been so much speculation. Just by the Jews' wailing place, on the outside of the temple, are the large skewbacks of an arch connecting the temple with Mount Moriah, Solomon's home. From the size of these skewbacks, the arch must have been a masterpiece of Phœnician work. Josephus speaks of this arch.

Damascus.—The Phœnicians founded Damascus, and the Phœnician gate, with its massive stones and grooves in which the door slid up and down, still exists. In what is said to be a triumphal arch, built like the façade of a Greek temple, occurs an arch sprung across on the two middle columns. The Greek square is carried over the arch. The arch is ancient, and no date can be assigned to it.

Baalbec.—In the foundation of the first temple of the Sun are found the three large stones about which the world is still puzzled to know how they were transported and elevated to their position. They weigh 1,000 tons each. One left in the quarry weighs 1,350 tons. The piers and arches supporting the temples are the counterpart of those under Solomon's temple at Jerusalem, and no doubt were erected by the same hands. They are as good to-day as when built, probably 3,500 years ago.

The second temple of the Sun, of which there are only six columns and frieze remaining, has no cella, and antedates the Roman temples which always have the cella. Its age is unknown and the style of architecture is in advance of the Greek corinthian, which has been copied from it and the fluting added to the columns. The workmanship of these ancient columns is unsurpassed. They are 7 feet 3 inches in diameter and 75 feet high.

The temple of Jupiter, built by Antoninus Pius, is the masterpiece of temples in design, material and workmanship. The columns, 6 feet 4 inches in diameter, were faced off absolutely true, and polished, so that when the two ends met they bore evenly over the whole surface. The polish on these columns is perfect after 1,800 years. Some of the columns overthrown in the earthquake 135 years ago show their construction. In the centre of each end of the sections of the column, was placed a large wrought-iron

dowel run up with lead. So well has this been done that one of the columns having been thrown over against the cella, is still leaning against it and does not come apart.

The quarries of Baalbec are the oldest in the world, and the manner of quarrying stone is the same as that of Assouan already described. It is the Phœnician method and was doubtless introduced into Egypt by this people, who were hired out to construct the great works of the old world. The Phœnicians were the master-builders of the world and taught the other nations their art. When the history of the nations comes to be written, the Phœnicians will be found in the advance for their influence on the arts of civilization.

CAUSES OF FIRES.

By C. John Hexamer.

[*Continued from p. 70.*]

I wish to call particular attention to the fact that the explosiveness of light petroleum products cannot be effectively lessened or neutralized by adding various substances to them. Numerous claims have been made for substances intended to be added to gasoline, and the naphthas, to reduce their explosibility. So far as I know there exists no substance which even to a slight degree lessens the inflammability of petroleum and its products. A stop should be put to the sale of such humbugs. The writer, in his experience as expert, has frequently found that people have become negligent and exceedingly careless in handling the light petroleum products, believing them to have been made safe by such additions. As a good thermometer is not accessible in every household, the simple test of pouring a few drops of the oil in a saucer and applying a match near the surface will suffice. If the material readily flashes and burns, reject it as unsafe.

In order to decrease the danger from lamps, so-called safety lamps have been invented. These are made of

glass, enclosed in metal cases, which protect the glass receptacles. Westland's lamp has, experimentally, proved successful, although the writer has no further evidence of how it has worked in practice. This lamp consists of a globe of glass, containing the oil, surrounded by a concentric sphere, containing water charged with carbonic acid gas under pressure. As soon, therefore, as the lamp is broken, carbonic acid gas is set free, tending to extinguish the flames.

Hanging lamps should be suspended from metal chains, and not from cords, for should the fibres burn through the lamp falls. Kerosene lamps should be filled in daytime only. Never attempt to fill a lamp while it is burning, or near an artificial light or fire. No flame, be it gas or oil, should be nearer than eighteen inches from bare woodwork at the sides and thirty-six inches from the ceiling.

Gasoline stoves are exceedingly dangerous and should not be used. In country residences, gasoline vapor, or, as it is frequently called, gasoline gas, is sometimes used. Where gasoline machines are used, the apparatus, especially the carburetting arrangement, should be placed at least fifty feet from all other buildings. The gas machine building should be on a piece of ground lower than the other buildings, so that the gasoline vapor which may escape, and which is heavier than air, may flow away from the buildings. Carefully see to it that all supply pipes descend towards the machine building, so that any vapor which may have condensed in its passage from the carburetter to the dwelling may flow back into the carburetter. Care must be taken to have a drip-cock attached to every jet, so that the pipes may be well emptied of gasoline before lighting the vapor. Gasoline vapor is extremely explosive and dangerous.

The electric light is daily coming more into use, and when properly installed is the safest. Great care should be taken to have all wires properly insulated, all connections in wires well made, the proper amount of cut-outs, switches and safety catches, and, for arc lights, provision should be made by wire guards to prevent the falling of the glowing

carbon points. One of the greatest hazards is caused by improper insulation, as moisture will cause an electric current to pass from one wire to another, especially through water which contains salts, such as lime, which it dissolves in passing through ceilings or walls.

Many fires are caused by matches, especially the so-called parlor or phosphorus match. These should always be kept in metal or earthen safes. Heavy earthen jars, with covers, are very good receptacles for them. All match safes should have covers. The most dangerous way of keeping them, is that often employed in dwellings, *i. e.*, in paper boxes, or loosely in kitchen-dresser drawers, in which they are often ignited by the motion of opening or shutting the drawer. Fires have been caused by matches through rats and mice. These vermin, by gnawing them, set them on fire, sometimes in the boxes, or at other times, after carrying them great distances through floors and hollow partitions to their nests, usually located near warm pipes.

So-called safety matches should, as far as possible, be employed. The safety match, which if I remember rightly, was first invented by Böttger, at Frankfort, in 1848, is now made of two kinds: those which are free from phosphorus, the amorphous variety of phosphorus being contained in the sand-paper; and secondly, those varieties which are free from phosphorus, both in the match and in the sand-paper. To the first kind belong matches made of a pasty mass, the main constituent of which is sulphuret of antimony and potassium chlorate. Secondly, the amorphous phosphorus, mixed with some very fine sand (or other substance which will be apt to promote friction), and with glue, and spread on the box in which the matches are contained. The friction surface on the box consists of nine parts of amorphous phorphorus, three parts of glass, seven parts of pulverized pyrites and one of glue. As is well-known, these matches can readily be ignited on surfaces containing this composition, but not when rubbed on other rough surfaces. These matches are now sold to a large extent in our country and are known as Swedish matches, as they are manufactured at Jönköping and are marked

"Säkerhets-tändstickor," meaning security fire matches. The matches belonging to the second category, *i. e.*, those which neither contain phosphorus nor require a phosphorus-coated surface, according to the analysis of Wiederhold, contain eight parts of chlorate of potassium, eight parts of sulphuret of antimony, eight parts of red oxide of lead and one part of gum senegal. Weiderhold suggested the following composition: chlorate of potassium, 7·8 parts; hyposulphite of lead, 2·6 parts; gum arabic, 1 part.

Matches are not a safe means for "lighting up," as it is more difficult to extinguish matches, especially the ordinary phosphorus match, than is generally believed, and if especial care be not taken to extinguish them, they glow for some time and frequently cause fires when carelessly thrown away.

In order to safely light gas, where permanent electric attachments have not been introduced, several devices have been constructed, among which are the electric torch. Other stationary devices, such as electric gas lighters attached to brackets or chandeliers, can be highly recommended for their great safety, and are now so cheap that there is no excuse for not installing them.

Smoking has frequently caused fires, especially in libraries and offices. The writer, several years ago, was called to investigate a case in which a gentleman thought that an amount of waste paper in his paper basket had been ignited by the concentrated rays of the sun through a defective window pane, which, as he believed, had acted as a lens, and thus ignited the paper; but upon further investigation a cigar stump was found in the bottom of the basket, among the burnt paper, and probably had been the originator of the fire. Great care should be exercised to place lighted cigars in metal or earthen receptacles. They should never be thrown away carelessly.

Wooden spittoons filled with saw-dust have caused fires, and cases have been observed where ignited spittoons burnt through floors and dropped into the cellar below. Such receptacles should be of metal or terra-cotta, and where an absorbent filling is desired, sand or gravel should be used.

It is a very bad and dangerous habit to smoke in bed, especially when indulged in as an antidote for alcoholic excesses. Fires and loss of life have been the consequence. Another cause of fires is reading in bed with lights near the bed-clothing.

Do not light pipes, cigars, gas, etc., with pieces of paper, and then carelessly throw these away without noticing whether they are extinguished. Persons frequently leave the room immediately thereafter, and the paper re-kindles. The draught produced by the opening and closing of the door may be sufficient to re-kindle smouldering paper.

One of the first requirements, not only of civilized life, but also to secure immunity from fire, is cleanliness. The fire hazard of any place increases with its untidiness. Not only should those places which are exposed to the view of strangers be kept clean, but especially those dark corners which would but seldom be noticed, such as lofts, out-of-the-way closets under stairways and cellars. It may relieve the dryness of this technical subject to note, *en parenthese*, that our ideals of cleanliness have been materially ameliorated, and are still improving. To quote Stevens, on the conditions of life in the time of Elizabeth and Shakespeare: "The sluttery of ancient houses rendered censers, or fire-pans, in which coarse perfumes were burnt most necessary utensils. Lodge tells us that Lord Paget's house was so small that 'after one month it would wax unsavory for hym to contynue in it.' In a letter of the Earl of Shrewsbury, respecting his prisoner, Mary, Queen of Scots, we read, 'That her majesty was to be removed for fyve or sixe days, to klense her chamber, being kept very unklenly:' and in the Memoirs of Anne, Countess of Dorset, we are informed of a party of lords and ladies, who 'were all lowsy by sitting in Sir Thomas Erskin's chamber.'"

Care must be taken to properly store waste paper clippings, straw, rubbish, or packing material, which may have been left in the house. Frequently this is put in places where it is exposed to heat, and liable to cause a fire.

When repairs are made, particular care should be taken to watch the workmen closely, so as to prevent them from

carelessly setting away tinsmiths' fire pots, plumbers' gasoline furnaces, and the like.

Spontaneous combustion is a frequent source of fire in dwellings. We shall treat this topic at length later, and therefore will not digress here, but give the caution to be careful of oily waste and rags, especially of the linseed oil rags left by painters, "finishers," etc.

It is a very hazardous practise to place clothing hung on clothes-horses, near stoves to dry (often done in wet weather) and leaving it there overnight. It seems like self-stultification to say that under no circumstances should clothing which has been cleansed by the lighter petroleum products, alcohol, chloroform, or ether, be placed near a fire, did we not know by sorry experiences that this is done. After cleaning clothing with such substances, which should never be done at night or near an artificial light or fire, they should be hung outside and thoroughly aired until there is no doubt that the volatile substance has vaporized. Not only numerous fires, but also serious explosions and loss of life, have been caused by carelessness in handling these products. The terrible accident that happened several years ago will be remembered, where several persons were killed by sprinkling benzine on a parlor carpet to preserve it against moths. The vapors escaped from the room, and travelled for some distance to the kitchen fire, causing a tremendous explosion, through which several unfortunates lost their lives. It must be well remembered that petroleum vapors are heavier than the air, and therefore do not readily escape through open windows. They sink to the floor, and if a light be placed near them, an explosion occurs.

Explosions have occasionally occurred of kitchen-range boilers, used for heating water, causing the fire in the range to be thrown out. Especial care should be taken to frequently change the water in the boiler on ironing days, when, through the great heat used to warm sad-irons, the waterback in the range is intensely heated, causing the water to be vaporized, and creating a considerable steam pressure in the boiler. To overcome this, one of the hot water spigots should be kept running continuously on such days,

so that steam which may have accumulated can escape. In winter time there is danger of explosion from the freezing of water supply pipes. Before firing up in cold weather, examine whether the water in the pipes is frozen; if this is the case, draw your fire and send for a plumber to thaw and repair the pipes before attempting to build a fire.

This series of articles has to do with fire hazards only, and we will not, therefore, treat of dwelling house construction here, which can better be done in a special essay; but we must touch on a topic demanding frequent and reiterated allusions by our daily and periodical press; that is, how to act in case of fire. For then even the coolest, metaphorically speaking, lose their heads, many become crazed with fright, and even strong men stand powerless as if stunned. He who remains most collected will be the one to render the most efficient service. Excited haste is almost as bad as no help; but the cool, rapid worker is the man needed in the work of saving. It is, for this reason, of importance that every person should exactly and frequently think about, and lay out his plans how he would work and act in case of fire. In going into a new house or hotel, he should find out where the fire escapes are located; how they are arranged; if they could be of value in case of fire, and not trust himself to the elevator for reaching and descending from his room, and then be entirely helpless in case of fire. The only way in which a person can be cool under trying circumstances, is by knowing exactly what to do at the time, as only the man who knows is self-reliant. In going into a theatre the same precaution should be taken. The writer has, in other papers read before the Institute, pointed out the fire hazards encountered in playhouses, and never settles in his chair when he visits a performance until he has satisfied himself of the most available exit from his location. All who value their own lives and the lives of those dependent on them, should do likewise.

A person should not only know the means of access to fire-escapes, stairways, and so on, but also how he may reach the roof of his dwelling place if his escape is cut off.

There is, I believe, a law in this city requiring trap-doors

on roofs; but numerous houses are without this essential. When a trap-door leads to the roof, a ladder (and a convenient one) should be permanently attached thereto. If this is not the case, the way to the roof is apt to be cut off at the very moment when it is most needed. A simple and reliable fire-escape should also be provided.

When a fire breaks out at night, do not stop to dress, but slip on shoes, wrap yourself in a blanket, not a cotton-filled quilt, and take the nearest and most accessible way to escape, bearing in mind that the shortest distance between two points is a straight line. In all cases be careful to close the doors after you. It is of the utmost importance to shut all doors and windows which might add to the draught. If the room be already filled with smoke, it is best for persons to crawl on their hands and knees on the floor, as the heated gases and smoke ascend and are more dense as they accumulate near the ceiling than they are at the floor. If the smoke is very suffocating, a piece of flannel (and if possible, a wet one), or any rag, woollen shirt or dress, held over the mouth and nose will greatly protect the lungs from injury. Avoid, as much as possible, inhaling the hot air and smoke.

If the means of escape through the doors on the first floor or the trap-doors on the roof, are cut off, and no fire-escape is at hand, hurry to the room least affected by smoke and hot air, and make a rope of shreds of bedding, attaching one end of the rope, and by this means try to descend to the ground. *Never jump from windows unless you are satisfied that all other means of escape are impossible.* If this is your only alternative, get persons on the outside to hold a carpet or a blanket, or even a large overcoat, and jump on it, or throw out bedding, mattresses, etc., and leap on these.

If a person's clothing has caught fire, wrap a blanket (not a cotton-filled quilt) around him quickly as this will exclude the air, and therefore the oxygen, and cause the fire to be extinguished. Woollen goods are to be preferred under such circumstances as they are less combustible, ammonium carbonate being given off during their ignition, which tends to retard and even extinguish flames; but in a case of this kind, one should never run out in the open air for aid as the

amount of oxygen fed to the flames will only be greater and cause the ignited garment to burn more furiously.

To extinguish fires, do not wait for the fire department to come. When a fire originates, immediately give the alarm before attempting to extinguish it yourself; then do not disdain to use even the simplest fire appliances at hand. A bucket of water thrown on during the first moments of ignition is worth more than all the fire engines in the city half an hour afterwards. Proceed on your hands and knees to where you think the fire originates, thus avoiding the smoke, and get as near as possible to the point of active combustion. Apply the water directly at the point of ignition and as near as possible to the bottom of the burning substance, as the water, which immediately vaporizes into steam, rises through the mass and tends to extinguish it much more effectually than by pouring the water on top of it.

Chimney fires can be readily extinguished by throwing salt down the chimney, as gas is evolved which extinguishes them.

Burning fats, rosins, pitch, etc., can be successfully extinguished by placing wire gauze of very fine mesh over the burning mass. The reason for this is (as is the reason for the efficiency of the Davy safety-lamp) that flames are not transmitted through wire gauze, as the wire being a good conductor, conducts away the heat, preventing the flames from passing. This remedy, however, is not usually available. Sand is a very good means for extinguishing fires originating in pitch, tar, petroleum and its products. Water is of little value; sand, on the other hand, when thrown on burning substances, cuts off the supply of oxygen from the air, causing the flames to be extinguished. If nothing better is at hand use a bucketful of ashes.

Do not, in case of fire, attempt to remove unnecessary or cumbersome articles. The writer has seen occurrences which were as absurd as that, frequently related, of the woman who attempted to save the mirror by throwing it out of a window from the top story and carried the bedding down-stairs.

We have in the United States devoted almost our whole attention, not so much to saving life in case of fire, as to extinguishing the fire, and for this reason, although we surpass the world in our appliances for extinguishment, we are far behind several European cities, such as the fire departments of Paris, Berlin, etc., in means for saving life.

Of all methods for saving life, the so-called "Rettungs-Schlauch," which means a life-saving hose, or, as it might be better translated, saving chute, has proved the best. It can in almost every case be used with safety for saving a number of persons. This device consists of a chute of heavy, strong sail cloth, and has been used to a height of eighty feet without danger of tearing. According to Magirus, a German authority on these matters, every metre of the chute should weigh at least 850 grammes, and it can be used, even at considerable heights, in an almost vertical position, but must then be turned spirally so as to allow the person in it to be shot through it slowly.

Unfortunately, at the time of the Ring Theatre fire, Vienna, they had but two of these devices, or many more persons would have been saved, as the apparatus did excellent service.

Timid or hysterical persons, objecting to enter the chute, should be forced into it. Of course, but one person at a time should be allowed to enter the chute. When cool, collected persons have charge of it a great number of lives can be saved in a short time. The number of persons which have thus been saved since its introduction about sixty years ago is astounding. Modifications of this old device have, I am told, been patented in this country, but these could be generally introduced without infringing any so-called "claims."

The invention of Hausmann and Richenberger is more recent; it consists of a cloth from 20 to 30 metres long and a width of from 300 to 320 centimetres, made of very heavy sail cloth. The person to be saved slides from a window into the middle of the inclined concave surface, and thereby, it is claimed, "slowly" slides down the middle of it.

The jumping cloth is an invention which has been used in Europe for a long time, and if it had not been for such aids many more would have been killed at the great theatre fire at Vienna. These cloths are generally three to four metres square, woven without a seam. In order to strengthen them from four to five belts or strips are tightly sewed onto the lower surface crosswise so that the cloth is subdivided into twenty-five equally large squares. It is then strongly hemmed in on all sides and a strong tarred rope with handles is tightly sewn on the edges. According to quality, a cloth of this kind costs from twenty to thirty-five marks. The cloths are held by persons on the street and those in danger jump into them. Of course, the second person is not allowed to jump until the first is removed from the cloth. There is but a slight danger connected with leaping into these, and thousands of persons have been saved by this contrivance. Had our police and fire department been supplied with such contrivances, we would have been spared the heartrending scenes at a Spruce Street dwelling house fire several years ago.

Several European fire departments have regularly drilled corps using small "hook ladders" which have been of excellent service. These ladders are light and strong, about twelve feet in length, with hooks at their ends. By attaching these to the windows a well-drilled corps can scale the highest building in an incredibly short time, carrying "saving chutes," etc., with them.

Numerous other inventions have been devised for saving life, but they are, as a rule, so complicated that it is utterly impracticable to use them. Inventors, as a rule, forget that an apparatus, which it is difficult to use, even at ordinary times, cannot be employed when people are frightened, and many fire-escapes can be seen on our streets at present which only a skilled acrobat could descend at his leisure in daylight, and are of no practical value. Many fire-escapes, although convenient, would soon become useless in case of fire. Thus we see some of them consisting of stairways enclosed with sheet iron, as for example the fire-escape on one of our largest hotels. The large sheet-iron boxes, in

case of fire, would act as excellent smoke flues, and people attempting to descend them would, in all probability, be suffocated. In order to keep people from falling, instead of sheet iron, a strong wire netting should be placed on the outside, which would not transform the escape into a smoke flue. The main ladder of a fire escape should never cross a window or other opening in a wall, as it would be impossible for persons to pass windows with the flames striking out of them. A light iron porch should be erected on every floor which should connect the windows with the main ladder. The best form of fire-escape is the brick tower, not permissible for dwellings, but its introduction should be made obligatory for hotels, tenements, etc. (An illustration is to be found in my paper, "The Construction and Interior Arrangement of Buildings Designed to be used as Theatres," this *Journal*, July, 1892.)

The appliances devised for saving one's self are, as a rule, of very little account. Several small devices have been invented, which, being simple, can be used by men, although it is not probable that women or children could use them.

Appliances which make it possible for firemen to breathe in compartments filled with smoke would be useful additions to our fire service, and would increase the efficiency of our firemen as life-savers. They have been used with success in Europe.

The first apparatus of this kind was devised by Colonel Paulin, Chief of the Paris Fire Department, between 1830 and 1845. It consists of a strong leather mask and blouse and a closed cape, into the inner part of which the smoke and hot gases from the fire cannot enter. Eyeholes, covered with strong glass plates, are inserted in the mask. In a position near the mouth a strong signal pipe is attached, while on the breast a leather hose two centimetres in diameter is connected with an air pump, which supplies the fireman using the device with air, and also the necessary oxygen for a lamp which is attached to the forepart of the suit.

Metz, the founder of the modern German Fire Department,

who first employed this apparatus in Germany, gave it a different form, by making it stronger and putting a cage in front of the glass eyepieces, so that these could not readily be broken. He attached the air tube in the back instead of the breast, which was more practicable, and replaced the blouse by an armor which went to the waist. Similar appliances with different improvements have also been made by Magirus, Kühfuss, Schultz, Hönig and Feltz.

It is important that fire departments, as well as the different police stations, should be well supplied with stretchers and implements for carrying away and properly attending to the wounded. Since the introduction of our police patrol service there has been a decided improvement in this respect. Would it not be possible to utilize these forces as life savers, equipped with the necessary appliances, at fires?

When a person has been partially suffocated with smoke or carbonic acid gas, place him on his back, with his head raised. Rinse the mouth and throat with water; sprinkle the head and face vigorously with cold water, and pour cold water over the body, open all tight garments, and continue the use of cold water until the arrival of a physician. When parts of the body are burnt, cover these with wadding or cloth saturated with linseed oil or lime water.

Every police patrol wagon and fire department station should be provided with a medicine chest, which should contain brandy, vinegar, alcohol, spirits of mustard, sal ammoniac, linseed oil, soda, burnt magnesium, sulphate of iron, peppermint tea, as well as a tourniquet and syringe, bandages, linen, brushes, sponges, shellac, etc., while a good supply of blankets, mattresses and stretchers, besides the above-mentioned saving devices, should not be wanting.

[*To be continued.*]

THE ACTION OF AMMONIA GAS UPON MOLYBDENYL CHLORIDE.

BY EDGAR F. SMITH AND VICTOR LENHER.

[*Read before the Chemical Section, May 16, 1893.*]

In 1857, Tuttle (*Annalen*, **101**, 285) studied the action of ammonia upon molybdenum trioxide, and molybdenum chloride ($MoCl_4$). In the case of the trioxide the temperature at which the reaction was made approached a red heat. The resulting product was in part black in color and possessed metallic lustre. Its analysis revealed the presence of nitrogen, oxygen, hydrogen and molybdenum. The quantity of the latter constituent equalled 92·9 per cent. Upon conductivity the reaction at more elevated temperatures, the product was found to contain 77·9 per cent. and 73 per cent. of molybdenum, while the hydrogen content did not exceed 0·18 per cent. The results consequently were not constant.

On exposing molybdenum chloride to the action of ammonia gas at a temperature just sufficient to volatilize the ammonium chloride which arose in the reaction, Tuttle obtained a black, metallic sintered mass. It was found to contain 82·83 per cent. of molybdenum and was assumed to have the composition expressed by the formula $Mo_2N_2 + Mo(NH_2)_2$, analogous to a compound of tungsten obtained in a similar manner by Wöhler (*Annalen*, **73**, 190).

Several years after the publication of the preceding investigation, Uhrlaub presented an inaugural thesis, entitled "Die Verbindungen einiger Metalle mit Stickstoff" (Goettingen, 1859), from which we collate the following interesting facts: In the action of ammonia gas in the cold upon molybdenum chloride much heat was evolved and a black colored product resulted; its analysis showed the presence of 76·457 per cent. of molybdenum, 23·134 per cent. of nitrogen and 0·677 per cent. of hydrogen. In subsequent experiment

Uhrlaub employed a more intense heat, thus hoping to eliminate the slightest hydrogen content, but this element continued to show itself in his various products, until on raising the tube in which the reaction took place to an intense red heat he obtained a compound that careful analysis gave a composition which may be expressed by the formula Mo_2N_3. In other words, a molybdenum nitride had been formed by acting upon the chloride of the metal with ammonia gas at a high temperature.

When Uhrlaub tried the action of ammonia upon molybdic acid at a gentle heat, he obtained "pseudomorphuen," as he designated them, bluish-black in color. Several were prepared; they varied much in composition. Uhrlaub attributes this variation to the different degrees of heat employed and to the length of time during which the heated molybdenum trioxide was exposed to the action of the gas.

The preceding facts indicate that the action of ammonia gas, either upon the trioxide or chloride, is not as simple as might be presumed. An amide that might well be expected in either case appears not to have been obtained by either Tuttle or Uhrlaub.*

We hope to reach this result by the action of ammonia gas upon molybdenyl chloride, in accordance with the equation

$$MoO_2Cl_2 + 4NH_3 = MoO_2(NH_2)_2 + 2NH_4Cl.$$

It will be noticed that we apply the term molybdenyl chloride to the compound generally called molybdenum dioxychloride. Our assumption of molybdenyl is based upon the terms sulphuryl, chromyl, etc., applied to compounds possessing a constitution similar to that of the dioxychloride of molybdenum MoO_2Cl_2, SO_2Cl_2, CrO_2Cl_2.

Preparation of Molybdenyl Chloride.—Of the various methods proposed for the formation of this derivative of molybdenum we discovered that the action of dry chlorine

* The primary object of these gentlemen seems to have been the preparation of molybdenum nitrides.

upon the dioxide of the metal yielded by far the most satisfactory product, both as to purity and quantity. At a very gentle heat the molybdenyl chloride forms rapidly and sublimes in feathery crystals. Schulze (*Jr. Prakt. Chemie*, **29** (N. F.), p. 440), in discussing the action of molybdic acid upon metallic chlorides, proposes this procedure for the object we had in view, but we failed to meet with success in our application of the method. The yield was not very abundant.

The crystalline molybdenyl chloride, prepared as described, was introduced into porcelain boats, and these placed in tubes of hard glass, through which we conducted a brisk current of well-dried ammonia gas. The molybdenyl chloride immediately assumed a deep-black color, much heat was evolved and copious fumes of ammonium chloride vapor were carried out of the tube. Considerable moisture also collected upon the anterior portion of the combustion tube. At last heat sufficient to expel any ammonium chloride retained by the compound was applied; but it was not for a longer period than half an hour. The boat and contents were cooled in ammonia gas. The product of the reaction was placed over sulphuric acid to absorb any retained gas; a portion of it was also washed with water, and the aqueous solution examined for chlorine, but this was not found present. In general appearance the product was metallic and black in color. Analyses were made of different preparations. The molybdenum content was determined by oxidizing weighed portions of material with dilute nitric acid, evaporating carefully to dryness, finally applying a gentle heat for a period of fifteen minutes.

The hydrogen was estimated by burning the material in a current of oxygen, and collecting the water that was produced in a weighed calcium chloride tube.

The nitrogen estimations were three in number; one of them was carried out by the method of Dumas, while the other two were made by the soda-lime process.

The oxygen was obtained by difference.

Our analytical results may be tabulated as follows :

Molybdenum Determination.

	MoO_2 found.		Mo Per Cent.
(1) 0·1047 gram substance taken, ...	0·1156 gr.	=	73·65
(2) 0·1006	0·1108 "	=	73·42
(3) 0·1004	0·1110 "	=	73·70
(4) 0·1028	0·1113 "	=	73·47
(5) 0·1017	0·1126 "	=	73·80

The mean molybdenum percentage of these five determinations is 73·61 per cent.

Hydrogen Determination.

	Water found.		H Per Cent.
0·2088 gram substance taken, ...	·0082 gr.	=	0·43

Nitrogen Determination.

	Pt. found.		N Per Cent.
(1) 0·1510 gram substance taken, ...	·0643 gr.	=	6·05
(2) 0·1529	·0642 "	=	5·96

The nitrogen found by the Dumas method equalled 6·00 per cent. and the mean of the three nitrogen estimations was also 6·00 per cent.

Two-thirds of this nitrogen content were expelled when our compound was exposed to the action of hydrogen at the highest temperature attainable with a good combustion furnace.

Taking the mean of our analyses as a basis of calculation :

	Per Cent.
Mo, ...	73·60
N, ...	6·00
H, ...	0·43
O (by difference), ...	19·96

we deduce $Mo_3O_8N_2H_3$ as the most probable empirical formula, which may be variously written to express the enigmatical constitution of this compound. Thus it might be $MoO(NH)_2$. $MoONH$. $3MoO_2$, or $4\ MoO_2$. $Mo(NH)_3$, which may be correctly termed tetramolybdenyl molylbdenimide.

Our compound is stable in the air. Hydrochloric acid does not affect it. Nitric acid of sp. gr. 1·42 causes it

to burn very energetically. Dilute alkalies attack it very sluggishly. It liberates ammonia when fused with caustic potash. When heated in a current of oxygen it is slowly oxidized. Heated in nitrogen gas the black compound loses water and assumes a reddish color. An analysis of this product indicates that it was probably molybdenum dioxide mixed with a very small amount of nitride; at least, traces of nitrogen were found upon examination. Another interesting observation was that when the black product was introduced into an aqueous solution of silver nitrate, crystals of metallic silver gradually appeared over the surface of the molybdenum compound.

We obtained our first product several times, but care must be exercised and the same conditions noted by us strictly observed if success in its formation is desired.

An examination of Uhrlaub's analytical results will show that one of his products approaches very closely the compound we have just described. He speaks of it as a black "pseudomorph" with the composition:

	Per Cent.
Mo,	73·55
N,	5·58
H,	0·54
O,	20·30

The formula deduced from these figures differs from that presented by us, and what is more, if we understand Uhrlaub correctly, his compounds, prepared from ammonia gas and molybdenum trioxide, were all "blau-schwarz" in color, and were not acted upon in the cold by nitric acid (see his dissertation, pp. 13, 14, 17).

However, it is evident that the product we obtained by the action of ammonia gas upon molybdenyl chloride is not the amide we had in view. Thinking that perhaps the heat we applied to drive out the final traces of occluded ammonium chloride may have been sufficient to alter the composition of the product formed at first, we allowed the ammonia to act upon the molybdenyl chloride at the ordinary temperature, and when there was no further evolution of ammonium chloride and the boat had become perfectly

cold* we introduced carbon dioxide, applying a very gentle heat at the same time, but we failed to achieve our aim. Nitrogen when substituted for carbon dioxide gave us no better result. We next dissolved molybdenyl chloride in the purest ether we could get and conducted ammonia gas into this solution. We obtained decomposition products. A closer examination of the behavior of the molybdenyl chloride towards ether revealed the fact that the moment the two came in contact a slight hissing sound was perceptible and the ether at once imparted a strong acid reaction to blue litmus. The same was observed when pure chloroform was employed as a solvent.

If molybdenyl chloride be gradually heated in an ammonia atmosphere until the tube of hard glass becomes bright red in color and the gas action be continued for the period of an hour, the resulting product will be an amorphous, metallic, black mass. Subjected to analysis it gave results as appended:

Molybdenum Determination.

	MoO_3 found.	Mo. Per Cent.
(1) 0·1042 gram substance taken, . . .	0·1061 gr.	= 67·87

Nitrogen Determination.

0·1025 gram substance burned with soda lime gave 7·00 per cent. N.

Hydrogen Determination.

0·1012 substance ignited in a current of oxygen gave ·0109 gram of water equal to 1·19 per cent. H.

	Per Cent.
Mo, ...	67·87
N, ...	7·00
H, ...	1·19
O (by difference), ...	23·94

The empirical formula deduced from these figures is $Mo_7O_{14}N_5H_{10}$, which can also be written

$$4MoO_3.2MoO_2(NH_2)_2.MoO_2NH_2$$

Dilute alkalies have no effect upon this compound; but

* Portions of the product removed at this stage and shaken with cold water decomposed into a mixture of blue- and brown-colored masses. The possibility of removing the ammonium chloride was, therefore, excluded.

it liberates ammonia when fused with caustic potash. It is converted into molybdenum trioxide very energetically—with evolution of sparks—when brought in contact with cold nitric acid.

Other products were obtained by us; their analyses lead us to the conclusion that with us as with Uhrlaub the composition of the derivative depended wholly upon the length of time during which the gas acted upon the molybdenyl chloride, and the degree of heat employed in the experiment. It seems highly improbable to us that the amide $MoO_2(NH_2)_2$—molybdenyl amide—can be prepared after the fashion pursued by us, for it is quite certain that the heat of the reaction evolved in the first contact of the ammonia with the molybdenyl chloride exercises a very potent influence upon the composition of the product.

When we recall the action of ammonia gas upon sulphur trioxide and sulphuryl hydroxy-chloride resulting in the compounds with the following constitution:

$$H_2N.SO_2\ OH$$

$$H\ N.<\begin{matrix}SO_2\ OH\\SO_2.\ OH\end{matrix}$$

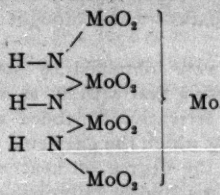
$$N—\begin{matrix}/SO_2\ OH\\SO_2.\ OH\\\backslash SO_2\ OH\end{matrix}$$

The question that obtrudes itself is: Are not these products and their methods of formation types of the processes and results that have occurred not only in our studies described in this paper, but also in the studies of Tuttle and Uhrlaub?* Are not their products as well as our own only residues of amide, imido, and nitrito molybdic acids?

Above we have written for our first product the constitutional formulæ $MoO(NH)_2$. $MoONH$. $3MoO_2$, and $4MoO_2$. $Mo(NH)_3$, but after considering the sulphur types we would

* At least in so far as the action of ammonia gas upon molybdenum trioxide was concerned.

express our empirical formula $Mo_8O_8N_2H_3$ differently, as follows:



We have here several broken-down molybdenyl amide nuclei in conjunction, not chemically combined, with metallic molybdenum. Reviewing the behavior of the product which we thus graphically represent, we may be allowed to emphasize the fact that when it was brought in contact with an aqueous argentic nitrate solution metallic silver was precipitated, and this we know from Smith's* observation is a property of metallic molybdenum. Further, it will be recalled that when our product was heated in an atmosphere of nitrogen it left a reddish-colored compound, which upon analysis approximated the requirements of molybdenum dioxide, and that traces of nitrogen were also detected in it. All these experimental facts find expression in our graphic representation above.

The second product obtained by us was even more active when introduced into a silver nitrate solution, throwing out metal quite rapidly, proving in our opinion the presence in it of even a greater quantity of metallic molybdenum than is contained in the first body. Similar reduced molybdenyl amide nuclei mixed with metallic molybdenum, could also be constructed for our second compound, and be in harmony with the observed deportment of this body if it were necessary.

UNIVERSITY OF PENNSYLVANIA,
PHILADELPHIA, May 16, 1893.

* *Zeitschrift für anorg. Chemie*, **1**, 360.

GELATINOUS SILVER CYANIDE.

By Lee K. Frankel.

[*Read before the Chemical Section, June 20, 1893.*]

In the *Comptes Rendus*, **73**, 998, Stas has described the occurrence of four different varieties of silver chloride, viz:

(*a*) the gelatinous;
(*b*) the cheesy, flocculent;
(*c*) the pulverulent;
(*d*) the granular crystalline variety.

No methods are given for obtaining these varieties, nor could the author find any reference in the literature to any other salts of silver having the above properties. The following will, therefore, be of interest.

Recently the author instructed one of the students in the University laboratory to reduce silver chloride to metallic silver by fusion with potassium cyanide. As the work was purely experimental, no weighed quantities of the substances were taken, nor was any notice taken of the temperature at which the fusion took place. The cooled mass and porcelain crucible were placed in a beaker, covered with water, boiled for thirty minutes, and then put aside until the following day. On examining the contents of the beaker, instead of finding the liquid above the crucible clear, as had been expected, it was filled with a transparent gelatinous mass, somewhat resembling aluminum hydrate, but of greater consistency. A portion of this precipitate was removed from the solution, carefully washed with cold water until the filtrate reacted neither with silver nitrate nor with dilute hydrochloric acid, and then carefully dried.

A qualitative examination showed the following: The substance is readily soluble in ammonium hydroxide, from which solution it is re-precipitated by nitric acid. It does not fuse on heating, but decomposes readily, leaving a residue of metallic silver. The presence of cyanogen was readily detected by the "prussian blue" reaction. No chlorine was found.

A quantitative estimation of the silver in the substance gave a result which was five per cent. lower than the theoretical amount of silver in silver cyanide.

This is in all probability due to the impurities contained in the compound, which arise from the potassium cyanide used in its preparation.

The amount of substance used in the analysis was very small, since what appeared to be a rather large quantity of the original, moist, gelatinous compound, shrivelled to a very small bulk on drying.

Repeated attempts have since been made to procure more of the substance for analysis, but all efforts have so far been futile. The amounts of silver chloride and potassium cyanide used have been varied, and the fusion likewise has been made at different temperatures, but without success. It is the intention of the author to fuse silver cyanide with potassium cyanide, and thereby to obtain the desired result.

UNIVERSITY OF PENNSYLVANIA,
PHILADELPHIA, June 15, 1893.

THE ELECTRICAL SECTION

OF THE

FRANKLIN INSTITUTE.

[*Proceedings of the stated meeting, held Tuesday, May 30, 1893.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, May 30, 1893.

ELMER G. WILLYOUNG, President, in the chair.

The Section's meeting of this date was called to order by President Willyoung, with an attendance of twenty members and visitors. The Treasurer reported a balance on hand of $17.09.

Mr. Willyoung reported that Prof. Elihu Thomson had written in response to the Section's invitation, that he was unable to appear at this time on account of prior engagements.

Mr. W. N. Jennings exhibited, by a projecting lantern, some lightning photographs. He first mentioned having shown before the Section, at its stated meeting of September 27, 1892, a number of these photographs, taken by him from a moving train, while crossing the prairies of North Dakota, being apparently single flashes, but giving multiple images of telegraph poles and

buildings. He stated that, at that time, from actual observation, he had come to the conclusion that lightning was a rapid oscillation or pulsation along a given path, and if the camera is moved during such a discharge, the resulting photograph would show a series of parallel lines, more or less numerous according to the rapidity of the camera movement. He now exhibited a photograph of a multiple flash of lightning taken from a moving train, the original flash appearing to the eye a single line of light, but in the photograph having even distinct lines, all having the same contour. He also showed a large "ribbon" flash of lightning, which effect, according to Tesla, Thomson, Young and others, was due to camera movement during the discharge. Mr. Jennings pointed out the fact that in the photograph, the telegraph poles, railroad ties and branches from the main stem of the discharge were all sharply defined, which led him to doubt the suggestion that the ribbon effect in this particular case was due to camera movement.

Mr. Thos. Spencer read a paper on "Some Interesting Peculiarities of Alternating Arc Lamps. It was referred for publication

The meeting then adjourned. ROBT. H. LAIRD, *Secretary*.

[*Proceedings of the stated meeting, held Tuesday, June 27, 1893.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, June 27, 1893.

ELMER G. WILLYOUNG, President, in the chair.

The stated meeting of the Section was called to order by President Willyoung, with an attendance of seventeen members and visitors.

Minutes of the previous meeting were read and approved. The Treasurer reported $36.09 on hand, and presented a bill for $3.20 for printing, which he was authorized to pay.

Mr. Paul A. Winand read a paper on "Rotary Magnetic Fields." It was referred for publication.

The President having been obliged to leave and neither of the Vice-Presidents being present, Mr. L. F. Rondinella was elected Chairman, *pro tem.*

It was moved that a vote of thanks be extended to the Secretary of the Institute for his courtesy in placing before the Section an exhibit of "Carborundum," and the data concerning some of its properties. The meeting then adjourned until September 26th. R. H. LAIRD, *Secretary*.

BOOK NOTICE.

Pumping Machinery. A practical hand-book relating to the construction and management of steam and power pumping machines. By William M. Barr. Philadelphia: J. B. Lippincott Company. 1893. pp. 447.

The scope of this work can be best described by the words of the author. The book is essentially descriptive of pump detail; no attempt has been made to enter into the theory and mathematics of pump construction. The volume has been prepared for the benefit of engineers, architects, contractors, etc., who have occasion to recommend and use pumping machinery, and who wish to inform themselves regarding pump construction. The book is divided into nineteen chapters, the first seven of which deal with the details of the design, the remainder treating of various classes of pumps and pumping engines, arranged according to the distinctive feature or special use to which they are applied.

Chapter I is used for introducing the subject generally, giving an idea of the various classes of pumps and data as to common practice in determining pressures for which the majority of pumps are made.

Chapter II treats of water pistons and plungers, giving clear sketches of the various forms in common use, the detail of making, securing and packing, and covering pistons, practically all forms of pumps in every-day use.

Chapter III treats of pistons and plunger rods, the material of which they should be made, the sizes in common use, the methods of securing them to the piston and of packing them.

Chapter IV treats of water valves and seats, the variation of pressure between the two sides of a valve, the materials of which valves are made, the method of securing them in place, of guiding them, of reducing the lift, and, in fact, of all the details that one not engaged in pump-making would be likely to inquire about.

Chapter V treats of air chambers. Chapter VI, of suction and delivery pipes, and Chapter VII of the design of the water end. The remaining chapter of the book treats of hydraulic pressure pumps, steam and power crank pumps, the duplex pump, compound direct-acting steam pumps, fire pumps, mining pumps, rotary pumps, centrifugal pumps, duty trials of pumping engines, direct-acting and fly-wheel high-duty pumping engines.

The book closes with an admirable index, making the work highly valuable for reference.

The amount of detail in this book is something unusual, and one reading it simply for general information fears to skip a page, as he might thereby lose a portion of the very interesting matter, of which the book is full. The name of the author above should be sufficient warrant that nothing but what was of permanent value would be found between its covers, and a careful reading convinces one that Mr. Barr has produced one of the most interesting and valuable works we have in English on an engineering specialty.

H. W. S.

PENNSYLVANIA STATE WEATHER SERVICE,

UNDER THE DIRECTION OF THE FRANKLIN INSTITUTE,

CO-OPERATING WITH THE

UNITED STATES DEPARTMENT OF AGRICULTURE, WEATHER BUREAU.

H. L. BALL, WEATHER BUREAU, OBSERVER IN CHARGE.

MONTHLY WEATHER REVIEW.

FOR MAY, 1893.

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, May 31, 1893.

GENERAL REMARKS.

The normal temperature for May is about 59°.3, and the normal precipitation, 4.09 inches. The following tables will show the departures of both temperature and rainfall during the month of May since the State Service has been in operation.

During the first and second decade the weather was cool, the minimum temperatures nearly all occurred during the first ten days; and at most stations in the mountains and in the northern counties, the mercury fell to and below the freezing point. More or less heavy frost occurred, but no great damage was reported. The warmest days were the 22d and 23d.

The rainfall was excessive at all stations and was pretty evenly distributed, except in the extreme northwestern and southeastern counties. In the former, exceedingly heavy rains occurred on the 16th; in the latter, the total rainfall was lighter than in any other part of the State. Following are the

dates on which excessive precipitation occurred (one inch in one hour or two and one-half in twenty-four hours):

Drifton, 3·10 inches, 24 hours, 4th.
Lancaster, 3·40 inches, 24 hours, 4th.
Lebanon, 3·01 inches, 24 hours, 4th.
Le Roy, 3·16 inches, 24 hours, 4th
Selins Grove, 3·57 inches, 24 hours, 4th.
Erie, 3·68 iuches, 24 hours, 16th.
Meadville, 3·32 inches, 24 hours, 16th.
Saegertown, 3·20 inches, 24 hours, 16th.
Dyberry, 1·25 inches, 30 minutes, 23d.

The heaviest hail storm ever experienced, in that vicinity, occurred at Pittsburgh on the 20th, from 3.45 to 3.50 P. M. Hailstones, irregular in form; largest, size of a hen's egg; average, about one inch in diameter. Great damage was done to property in the city, apparently the storm being heaviest there. No serious injury to crops was reported.

From January 1, 1893, to May 31, 1893, the deficiency in temperature at Philadelphia was 353°, at Erie 408°, and at Pittsburgh 359°.

For the same period the excess in precipitation at Philadelphia was 1 81, at Erie 5·76, and at Pittsburgh 2·76 inches.

	Mean Temperature.	*Mean Precipitation. Inches.*
May, 1888,	57°·6	4·24
1889,	62°·0	5·91
1890,	58°·8	6·71
1891,	57°·5	2·12
1892,	59°·5	5·70
1893,	58°·0	5·54

TEMPERATURE.

The mean temperature for May, 1893, was 58°·0, which is about 1°·3 below the normal, and 1°·5 below the corresponding month of 1892.

The mean of daily maxima and minima temperatures, 68°·8 and 47°·0, gives an average daily range of 21°·8, and a monthly meap of 57°·9.

Highest monthly mean, 65°·4 at Kilmer.

Lowest monthly mean, 50°·9 at Wellsboro.

Highest temperature recorded during the month, 93°·0 on the 23d at Kilmer.

Lowest temperature, 26°·0 on the 8th at Wellsboro.

Greatest local monthy range, 60° at Hollidaysburg.

Least local monthly range, 44° at West Chester.

Greatest daily range, 57° at Hollidaysburg on the 20th.

Least daily range, 2° at Aqueduct on the 17th and Salem Corners on the 4th.

BAROMETER.

The mean pressure for the month, 29·91 is about ·09 below the normal. At the United States Weather Bureau Stations the highest observed was 30·39 at Harrisburg on the 10th, and the lowest, 29·34 at Erie on the 16th.

PRECIPITATION.

The average precipitation, 5·54 inches for the month, is an excess of about one and one-half inches. The largest totals in inches (including melted snow) were Blue Knob, 9·20; Drifton, 8·94; Saegertown, 8·89; and Girardville, 8·51. The least were Philadelphia (Weather Bureau) 2·92; Philadelphia (Centennial Avenue), 3·12; Westtown, 3·15, and Philadelphia (Locust Street) 13·37 inches.

WIND AND WEATHER.

The prevailing wind was from the Northwest.

Average number: Rainy days, 12; clear days, 11; fair days, 8; cloudy days, 12.

MISCELLANEOUS PHENOMENA.

Thunder-storms.—Blue Knob, 5th, 12th, 13th, 20th, 23d; Hollidaysburg, 1st, 12th, 20th, 31st; Le Roy, 23d; Quakertown, 1st, 23d; Johnstown, 1st, 5th, 12th, 20th, 31st; Emporium, 23d; East Mauch Chunk, 16; State College, 1st, 20th, 23d, 31st; Coatesville, 5th, 23d; Kennett Square, 5th, 21st, 23d; Phœnixville, 23d; Grampian, 23d; Lock Haven, 20th, 23d, 31st; Bloomsburg, 1st; Meadville, 1st, 15th, 20th, 31st; Carlisle, 5th, 20th, 23d; Edinboro, 12th, 15th, 20th, 28th, 31st; Chambersburg, 2d, 5th, 13th, 20th, 23d; Huntingdon, 1st, 5th, 20th, 31st; Kilmer, 1st, 5th, 20th, 23d, 31st; Lancaster, 23d; Lebanon, 1st, 13th, 20th, 23d; Coopersburg, 2d; Wilkes-Barre, 1st, 23d; Smethport, 12th, 20th; Easton, 10th, 14th, 23d; Aqueduct, 1st, 5th, 20th, 23d, 31st; Philadelphia, 23d; Centennial Avenue, 5th, 16th, 23d; Locust Street, 21st, 23d; Girardville, 3d, 23d; Selins Grove, 5th, 31st; Somerset, 1st, 5th, 12th, 17th, 20th, 21st, 23d, 31st; Wellsboro, 23d, 31st; Lewisburg, 1st, 23d, 30th, 31st; Columbus, 15th, 23d, 31st; Dyberry, 23d, 30th, 31st; Salem Corners, 1st, 24th; Ligonier, 20th; South Eaton, 22d, 30th, 31st; York, 5th, 23d.

Hail.—Blue Knob, 4th; Le Roy, 23d; Edinboro, 15th; Huntingdon, 13th, 31st; Somerset, 5th, 31st; Lewisburg, 23d; Ligonier, 20th.

Snow.—Blue Knob, 4th.

Frost.—Blue Knob, 7th; Hollidaysburg, 7th, 8th, 18th, 19th, 20th; Johnstown, 7th, 8th, 19th, 20th; Emporium, 8th, 9th, 10th, 19th, 20th, 22d; State College, 8th; Coatesville, 8th, 9th, 20th; Kennett Square, 8th; Lock Haven, 19th, 20th; Meadville, 19th; Huntingdon, 7th, 8th, 19th, 20th; Kilmer, 7th, 20th; New Castle, 7th, 19th; Lebanon, 8th; Smethport, 19th, 20th; Girardville, 4th, 8th; Selins Grove, 6th, 8th, 20th; Somerset, 5th, 6th, 7th; Wellsboro, 5th, 7th, 8th, 19th, 20th, 22d, 29th, 31st; Columbus, 8th, 19th; Dyberry, 8th, 20th, 25th; Honesdale, 8th, 20th; York, 7th, 8th.

Auroræ.—Le Roy, 7th; Quakertown, 14th; Coatesville, 13th.

Coronæ.—Blue Knob, 27th; Quakertown, 22d; Emporium, 27th; Lebanon, 21st, 22d, 23d, 30th; Philadelphia (Centennial Avenue), 22d, 30th; Dyberry, 19th.

Monthly Summary of Reports by Voluntary Observers of

County.	Station.	Elevation above Sea Level (feet).	Barometer Reduced to Sea Level.			Temperature.								
							Maximum.		Minimum.					
			Mean.	Highest.	Lowest.	Mean.	Highest.	Date.	Lowest.	Date.	Mean of Maximum.	Mean of Minimum.	Mean.	Greatest.
Allegheny,	Pittsburgh, A,	820	29·32	30·35	29·46	59·6	85	22	38	7	69·7	49·5	59·2	36
Berks,	Hamburg,	380	. . .	. . .	. . .	59·9	88	23	38	20	70·7	49·2	21·5	42
Berks,	Reading, A,	280	. . .	. . .	. . .	. . .	. .	. .	. .	. .	. .	. .	. .	.
Blair,	Altoona, B,	1,181	. . .	. . .	. . .	62·5	89	24	40	8	71·8	53·2	18·6	37
Blair,	Blue Knob, A,	2,500	. . .	. . .	. . .	57·0	82	22	28	7	63·9	50·2	13·7	32
Blair,	Hollidaysburg,[1]	947	. . .	. . .	. . .	58·4	89	20	29	8	72·3	42·5	29·8	57
Bradford,	Wysox[2] (26 days),	718	29·91	30·40	29·31	58·8	89	23	32	20	69·2	43·1	26·1	47
Bradford,	Le Roy,	1,400	. . .	. . .	. . .	55·6	84	23	36	8	65·1	46·1	19·0	33
Bucks,	Forks of Neshaminy[1] (26 days),	304	. . .	. . .	. . .	58·1	. .	. .	. .	. .	. .	. .	. .	.
Bucks,	Quakertown,[1]	536	29·95	30·36	29·43	57·3	86	23	36	8	69·1	46·6	22·3	37
Cambria,	Johnstown, A,	1,284	. . .	. . .	. . .	. . .	. .	. .	. .	. .	. .	. .	. .	.
Cameron,	Emporium, A,	1,050	29·89	30·36	29·23	56·8	89	23	31	8	69·4	44·2	25·2	48
Carbon,	E. Mauch Chunk,	550	. . .	. . .	. . .	58·5	89	23	37	20, 20	69·6	47·4	22·2	43
Centre,	State College— Agricultural Experiment Station,	1,191	29·85	30·33	29·28	57·4	85	23	31	4	67·2	45·8	21·4	40
Chester,	West Chester,[1]	453	29·90	30·34	29·34	59·2	86	23	42	4, 8	68·7	50·0	18·7	32
Chester,	Coatesville,[1]	380	. . .	. . .	. . .	59·8	87	21, 23	35	8	71·1	47·4	23·7	42
Chester,	Kennett Square, A,[2]	375	. . .	. . .	. . .	57·7	. .	. .	. .	. .	. .	. .	. .	.
Chester,	Phœnixville, A,	190	29·92	30·38	29·38	60·4	87	21, 23	39	8	70·2	50·5	19·7	35
Chester,	Westtown,	350	. . .	. . .	. . .	58·0	87	23	30	1	68·6	47·5	21·1	41
Clearfield,	Grampian,[e1]	1,450	. . .	. . .	. . .	56·1	86	23	34	8	67·3	47·5	19·8	42
Clinton,	Lock Haven,[1]	560	. . .	. . .	. . .	58·4	92	23	33	8	72·4	44·3	28·1	50
Columbia,	Bloomsburg, A— State Normal School,	500	29·73	30·26	29·21	57·9	84	22	35	8	68·4	47·3	21·1	40
Crawford,	Meadville— Divinity Hall,[1]	1,200	. . .	. . .	. . .	55·2	85	22	34	7	67·6	45·3	22·3	33
Crawford,	Saegertown, A,	1,200	. . .	. . .	. . .	53·5	82	22, 23	30	8, 19	66·5	40·5	26·0	45
Cumberland,	Carlisle,[1]	480	. . .	. . .	. . .	58·2	88	21, 23	31	8	70·7	48·1	24·6	41
Dauphin,	Harrisburg, A,	361	29·92	30·38	29·36	59·0	86	23	41	4	67·6	50·3	17·2	28
Delaware,	Swarthmore, A— Swarthmore College,	190	29·89	30·33	29·34	61·2	88	22	43	10, 11	70·9	51·5	19·4	36
Erie,	Edinboro,[e1]	1,400	. . .	. . .	. . .	53·0	75	8, 22	33	5, 8	. . .	. . .	. .	.
Erie,	Erie, A,	681	29·89	30·31	29·34	54·0	85	23	38	6	62·0	46·0	16·0	32
Fayette,	Uniontown,[1]	1,000	. . .	. . .	. . .	59·2	83	20, 22	37	19	65·0	49·5	15·5	31
Franklin,	Chambersburg,[2]	618	. . .	. . .	. . .	59·8	88	23	38	8	. . .	. . .	. .	.
Fulton,	McConnellsburg,[1]	875	. . .	. . .	. . .	59·3	88	23	35	7, 8	71·2	46·4	24·8	41
Huntingdon,	Huntingdon, A— The Normal College,	650	. .	. .	. . .	58·7	90	23	31	8	72·1	45·3	26·8	5
Indiana,	Indiana— State Normal School,	1,350	. . .	. . .	. . .	. . .	. .	. .	. .	. .	. .	. .	. .	.
Juniata,	Kilmer,[2]	475	. . .	. . .	. . .	65·4	93	23	48	4, 20	. . .	. . .	. .	.
Lancaster,	Lancaster, A— Franklin and Marshall College,	413	29·91	30·37	29·37	58·4	86	23	37	7	69·8	47·1	22·7	3
Lawrence,	New Castle,[1]	932	. . .	. . .	. . .	59·7	86	22	28	7	68·8	42·4	26·4	4
Lebanon,	Lebanon, A,	458	29·90	30·36	29·36	58·4	86	21	33	8	68·5	48·3	20·2	4
Lehigh,	Coopersburg,[1]	550	. . .	. . .	. . .	58·7	84	11, 22	30	8	68·4	49·4	19·0	3
Luzerne,	Drifton (24 days), A,	1,683	29·88	30·29	29·36	53·9	83	22, 23	32	8, 20	66·1	41·7	24·4	4
Luzerne,	Wilkes-Barre, A,	575	. . .	. . .	. . .	61·6	91	12, 23	33	8	77·2	45·9	31·3	4
McKean,	Smethport (29 days), A,	1,500	. . .	. . .	. . .	53·1	82	22	27	8	66·0	40·3	25·7	4
Montgomery,	Pottstown,	150	. . .	. . .	. . .	61·7	89	21	40	9	71·7	51·7	20·0	3
Montgomery,	Skippack, A (27 days),	. .	. . .	. . .	. . .	59·6	84	21	34	7	69·4	49·8	19·6	3
Northampton,	Easton— Lafayette College,	325	. . .	. . .	. . .	58·9	86	23	37	7	68·7	49·1	19·6	3
Perry,	(Aqueduct) Logania,[e1]	367	. . .	. . .	. . .	60·4	90	23	36	20	71·3	49·4	22·1	4
Philadelphia,	U. S. Weather Bureau, A,	117	29·91	30·38	29·36	61·0	89	23	43	4	69·6	52·3	17·3	2
Philadelphia,	1529 Centennial Avenue, A,	120	29·91	30·38	29·35	61·4	89	23	44	3, 8	70·9	52·0	18·9	3
Philadelphia,	3911 Locust Street, A,	. .	. . .	. . .	. . .	60·8	88	23	43	5	70·2	51·4	18·8	3
Pike,	Blooming Grove,[e1]	. .	. . .	. . .	. . .	57·3	88	22	29	7	. . .	. . .	. .	.
Schuylkill,	Girardville[1] (28 days),	1,000	29·84	30·31	29·29	57·8	85	23	37	8	68·1	45·5	21·6	3
Snyder,	Selins Grove, A,	435	29·92	30·38	29·35	59·4	90	23	33	8	70·4	48·3	22·1	3
Somerset,	Somerset,[1]	2,250	. . .	. . .	. . .	54·7	83	11, 22	31	7	67·8	43·6	22·2	4
Tioga,	Wellsboro,[e1]	1,327	. . .	. . .	. . .	50·9	84	23	26	8	61·3	38·2	23·1	4
Union,	Lewisburg, A,	450	29·88	30·28	29·40	57·6	86	22, 23	31	8	69·7	45·5	24·2	4
Warren,	Columbus,	1,410	. . .	. . .	. . .	. . .	. .	. .	. .	. .	. .	. .	. .	.
Wayne,	Dyberry,[1]	1,100	. . .	. . .	. . .	54·4	86	23	31	20	65·0	45·0	20·0	4
Wayne,	Honesdale,[1]	1,000	. . .	. . .	. . .	55·7	85	23	33	8	65·6	45·9	19·7	4
Wayne,	(Salem Corners) Hamlinton,[1]	1,600	. . .	. . .	. . .	54·4	88	23	34	8	63·7	48·1	15·6	3
Westmoreland,	(Immel Reservoir) Lycippus,[e1]	1,420	. . .	. . .	. . .	58·1	76	22	45	7, 24	. . .	. . .	. .	.
Westmoreland,	Ligonier (27 days),	1,750	. . .	. . .	. . .	55·9	87	23	30	19	69·0	43·8	25·2	5
Wyoming,	South Eaton, A,	660	. . .	. . .	. . .	56·6	82	21	33	8	67·0	46·2	20·8	4
York,	York, A,	385	29·87	30·27	29·34	59·7	88	23	35	8	71·6	47·8	23·8	4

A, Observations taken at 8 A. M. and 8 P. M. B, Observations taken at 12 Noon. * Extremes from dry thermometers. † Mean temperatures, 7 + 2 + 9 + 9

Daily Range.				Relative Humidity.	Dew Point.	Precipitation.				Number of Days.				Wind.			Observers.
														Prevailing Direction.			
Greatest.	Date.	Least.	Date.			Total Inches.	Total Snowfall During Month.	Depth of Snow on Ground at End of Month.	Number of Days Rainfall.	Clear.	Fair.	Cloudy.	7 A. M.	2 P. M.	9 P. M.	
36	20	5	17	74·0	51·3	4·50	. . .	. . .	18	7	11	13	NW	NW	NW	O. D. Stewart, Weather Bureau.
42	20	3	16, 17	. . .	. . .	6·80	. . .	. . .	22	5	15	11	NW	W	SW	William Shipe.
. . .	. . .	. . .	. . .	. . .	. . .	4·44	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	Franklin Yager.
37	24	10	27	. . .	. . .	4·67	. . .	. . .	14	. . .	. . .	. . .	. . .	. . .	. . .	Dr. C. B. Dudley.
32	7	3	16, 17	. . .	. . .	9·20	. . .	. . .	18	9	20	22	NW	NW	NW	A. H. Boyle.
57	20	8	17	. . .	. . .	5·23	. . .	. . .	17	13	10	8	NW	W	W	Prof. J. A. Stewart.
47	20	8	16	79·0	50·9	3·65	. . .	. . .	8	20	2	14	NW	NW	NW	Charles Beecher.
33	20	4	18	. . .	. . .	7·76	. . .	. . .	13	9	11	11	SW	SW	SW	G. W. T. Warburton
. . .	. . .	. . .	. . .	. . .	. . .	4·22	. . .	. . .	10	10	10	6	W	E	W	J. C. Hilsman.
37	23	7	27	76·6	49·8	5·41	. . .	. . .	14	11	9	11	SW	NW	SW	J. L. Heacock.
. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	E. C. Lorentz.
48	20	8	17	75·0	49·9	4·39	. . .	. . .	19	7	10	14	W	. . .	W	T. B. Lloyd.
43	20	4	17	. . .	. . .	6·68	. . .	. . .	20	13	6	12	W	W	W	F. C. Wintermute.
40	20	8	3, 17	72·1	47·6	6·46	. . .	. . .	15	8	7	16	W	SW	W	Prof. Wm. Frear.
32	20	6	27	68·0	48·4	4·18	. . .	. . .	14	17	3	11	W	NW	SE	J. C. Green, D.D.S.
42	20	7	27	. . .	. . .	3·86	. . .	. . .	11	13	8	10	W	W	W	W. T. Gordon.
. . .	. . .	. . .	. . .	. . .	. . .	3·61	. . .	. . .	9	16	6	9	NW	. . .	SW	B. P. Kirk.
35	20	6	1	72·1	51·2	4·64	. . .	. . .	12	13	6	12	NW	. . .	NW	Knowles Croskey.
47	21	6	27	. . .	. . .	3·15	. . .	. . .	6	20	4	7	SE	. . .	. . .	Harry Alger.
22	20	4	17	. . .	. . .	5·47	. . .	. . .	13	6	10	15	W	W	W	Nathan Moore.
50	20	6	3	. . .	. . .	4·89	. . .	. . .	16	13	7	11	W	W	W	Prof. J. A. Robb.
40	20	5	3	81·2	59·0	7·07	. . .	. . .	13	8	8	15	W	. . .	W	Prof. J. G. Cope.
33	29	5	17	76·4	49·0	7·48	. . .	. . .	13	6	7	18	SW	W	SW	Chas. Graves.
45	22	6	17	. . .	. . .	8·89	. . .	. . .	22	9	9	13	NW	. . .	NW	J. G. Apple.
41	11	6	17	. . .	. . .	5·49	. . .	. . .	12	9	10	12	S	SW	S	J. E. Payne.
38	20	3	17	74·8	50·0	5·32	. . .	. . .	16	10	6	15	W	W	W	F. Ridgway, Weather Bureau.
36	21	4	17	75·0	51·0	3·48	. . .	. . .	8	6	18	7	NW	. . .	SW	Prof. Susan J. Cunningham.
. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	C. F. Sweet.
36	23	4	17	73·0	45·0	7·39	. . .	. . .	14	7	11	13	W	W	W	P. Wood, Weather Bureau.
37	20	3	17	. . .	. . .	5·68	. . .	. . .	17	10	16	5	SW	SW	NW	Wm. Hunt.
. . .	. . .	. . .	. . .	. . .	. . .	6·24	. . .	. . .	10	12	8	11	W	. . .	W	G. W. Ludwig.
45	20	4	18	71·3	50·0	6·20	. . .	. . .	15	11	11	9	W	W	NW	T. F. Sloan.
53	20	8	17	. . .	. . .	7·79	. . .	. . .	17	13	5	13	W	. . .	W	Prof. W. J. Swigart.
. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	Prof. S. C. Schmucker.
. . .	. . .	. . .	. . .	. . .	. . .	6·32	. . .	. . .	12	7	14	10	W	W	W	R. J. Mickey.
39	20	5	28	71·2	48·8	6·96	. . .	. . .	13	15	6	10	W	. . .	W	W. E. Bushong.
46	22	8	4	. . .	. . .	6·23	. . .	. . .	9	9	6	16	W	W	W	Wm. T. Butz.
41	20	6	17	76·8	50·0	8·05	. . .	. . .	18	11	7	13	SW	. . .	SW	G. W. Hayes, C.E.
34	20	3	27	. . .	. . .	5·42	. . .	. . .	13	13	8	10	NW	NW	SE	Dr. M. H. Boye.
46	10, 11	5	17	71·0	48·0	8·94	. . .	. . .	8	10	4	16	. . .	. . .	. . .	J. R. Wagner.
49	20	17	4	. . .	. . .	4·15	. . .	. . .	8	21	4	6	SW	. . .	SW	A. W. Betterly.
49	20	3	17	. . .	. . .	4·90	. . .	. . .	11	11	8	12	W	. . .	SW	Armstrong & Brownell.
33	11	4	27	69·3	49·8	4·80	. . .	. . .	9	18	4	9	NW	S	W	Charles Moore, D.D.S.
38	10	4	18	. . .	. . .	. . .	. . .	. . .	. . .	16	4	7	W	. . .	. . .	B. W. Dambly.
31	23	6	3, 27	. . .	. . .	4·82	. . .	. . .	9	10	7	14	. . .	. . .	. . .	J. W. Moore.
43	20	2	17	. . .	. . .	6·40	. . .	. . .	13	11	10	10	S	. . .	. . .	Richard Callin.
29	2	5	3	65·0	48·0	2·98	. . .	. . .	8	18	6	13	SW	SW	SW	L. M. Dey, Weather Bureau.
30	2	5	27	67·0	48·3	3·12	. . .	. . .	8	15	5	11	SW	. . .	SW	John Comly.
30	11	6	3, 27	. . .	. . .	3·37	. . .	. . .	11	11	5	15	SW	. . .	SW	Ralph L. Paddock.
. . .	. . .	. . .	. . .	. . .	. . .	6·72	. . .	. . .	7	. . .	. . .	. . .	. . .	. . .	. . .	John Grathwohl.
37	20	5	17	. . .	. . .	8·51	. . .	. . .	10	19	7	9	W	NW	NW	S. C. Wagner.
38	22	7	10	92·2	54·2	6·85	. . .	. . .	14	0	19	12	SW	. . .	SW	J. M. Boyer,
48	20	5	17	89·1	37·1	7·30	. . .	. . .	18	9	5	17	SW	SW	SW	W. M. Schrock.
. . .	. . .	. . .	. . .	. . .	. . .	6·58	. . .	. . .	13	7	3	21	N	S	W	H. D. Deming
46	20	7	17	91·2	53·8	6·48	. . .	. . .	11	10	10	11	SW	. . .	SW	Prof. W. G. Owens.
. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	Wm. Loveland.
47	20	3	4, 16	. . .	. . .	6·21	. . .	. . .	12	7	10	14	W	W, NW	W, NW	Theodore Day.
36	11	4	4	. . .	. . .	5·70	. . .	. . .	12	. . .	. . .	. . .	. . .	. . .	. . .	John Torrey.
34	23	9	4	. . .	. . .	5·21	. . .	. . .	16	6	10	15	W	W	W	T. B. Orchard, M.D.
. . .	. . .	. . .	. . .	. . .	. . .	5·60	. . .	. . .	12	. . .	. . .	. . .	. . .	. . .	. . .	Murray Forbes
50	20	5	17	. . .	. . .	8·13	. . .	. . .	16	8	12	7	. . .	. . .	. . .	J. T. Ambrose.
40	20	7	14	. . .	. . .	5·19	. . .	. . .	9	13	3	15	S	. . .	NW	B. M. Hall.
43	20	8	17	83·8	53·2	6·53	. . .	. . .	15	15	5	11	NW	. . .	NW	Mrs. L. H. Grenewald.

[1] 9 + 9 + 4. [2] Mean of 8 + 8 + 2. [3] Mean of 7 + 7 + 2. Absence of numerals indicates that mean of temperature is from maximum and minimum readings.

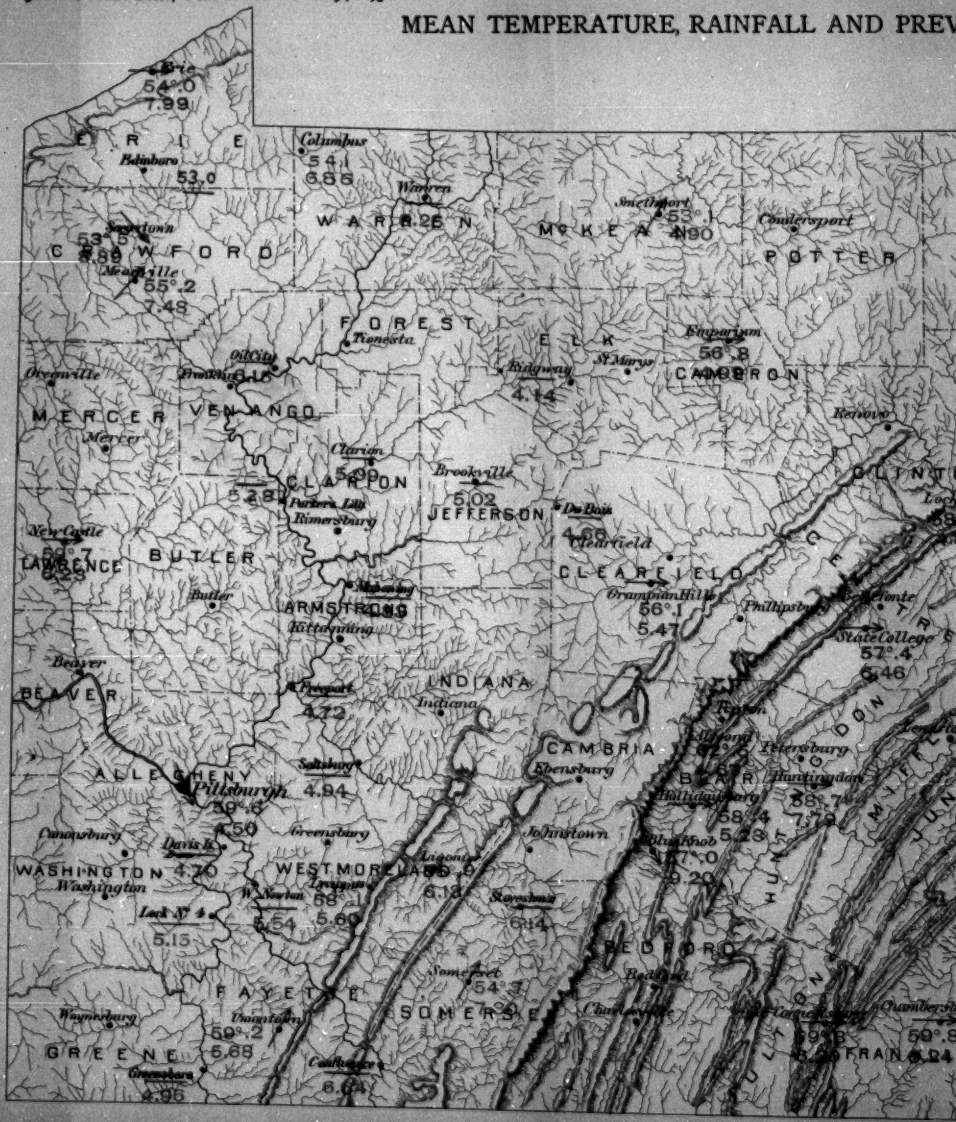
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Total.
Delaware Basin.																																
Blooming Grove,	.94			2.40		.25								.22		1.23						1.50			.18							6.72
Browers Lock,			.71	1.75		.49										.61								.42				.20				4.08
Coatesville,	.09		.93	.95	.22	.26								.05	.11	.20					.03		.88					.14				3.86
Coopersburg,	.67	.10	1.57	1.02	.03	.42								.25	.05	1.02					.01		.16			.02		.10				5.42
Doylestown,	.35		1.00	.79		.28										1.55												.04				4.28
Dyberry,	.35	.10	.28	1.46										.28		.25	.30	.37					1.25			.40				.76	.21	6.21
Easton,	.30			2.16		.60								.21		1.03	.01							.31				.05	.15			4.82
Forks of Neshaminy,	.28	.03	.84	.94		.52										1.00		.08						.49				.02	.28			4.22
Frederick,	.66	.05	.90	1.33		.32								.09	.04	.54							.28					.05	.05			4.51
Hamburg,	.56	.26	.98	1.52		.81								.24		.96	.01				.14		.96			.18		.20				6.82
Honesdale,	.55		.50	1.69	.06	.68								.25		.77	.05	.01					.82			.39				.33		5.70
Kennett Square,			.80	1.04		.60								.05	.03	.42								.52				.04	.11			3.01
Lansdale,	.42	.08	.78	.70												1.32								.25				.04				3.58
Mauch Chunk,	.26	.85	.70	2.25		.56								.03		1.11	.05							1.30		.05			.15			6.68
Ottsville,			2.20	.47		.46								.02		1.29							.20				.15	.06				4.85
Philadelphia, a†	.01		.59	.69		.47										.67								.26				.04	.19			2.92
Philadelphia, b,	.03		.83	.78		.49										.76		.02										.05	.16			3.12
Philadelphia, c,	.02		.83	.79		.50								.01	.01	.64		.02						.28				.05	.20			3.37
Phœnixville,	.13	.03	1.17	1.83		.40								.03	.04	.48							.09	.30		.04		.10				4.64
Point Pleasant,	.15	.16	1.00	.90	.49											2.17											.17					5.04
Pottstown,	.38		1.37	1.60		.45								.20	.15	.35							.35			.05						4.80
Quakertown,	.44	.09	1.16	1.15	.12	.40								.25	.15	1.26							.18	.01		.06	.02	.04				5.41
Reading,	.22	.05	1.05	1.78		.30								.02	.01	.42	.01			.01	.01		.25	.07		.01	.02	.01				4.44
Salem Corners,	.22	.58	.06	2.10	.20	.10	.02							.28	.10	.15	.52	.05	.03				.55				.23	.02				5.21
Seisholtzville,	.72		1.36	1.36		.52										1.26							.29				.10					6.21
Smith's Corner,	.40	.06	1.10	.70		.49										1.72							.12					.05				4.64
Swarthmore,			1.00	.60		.53								.02	.03	.65								.47			.18					3.48
West Chester,	.06		1.10	1.11	.13	.43								.03		.44		.01			.01		.30	.09			.07	.15				4.18
Westtown,																																
Susquehanna Basin.														.05		.25	.35						.00							.13		3.15
Altoona,	.35	.64	.18	•	1.10	.75								.07	.15		.56	.08			.44			.08			.09	.14				4.67
Aqueduct,	.70		1.40	.50	1.00									.33	.05	.22	1.50	.08								.18		.01				6.40
Bloomsburg,	.30	.21	.47	2.18		.21								.07	.87		1.41	.12			.07		.43			.20	.03					7.07
Blue Knob,	.47	.89	.82	1.07	.36										.47	.03	.53	.56	.51		.73		.11			.19	.11	.22	.04		1.85	9.80
Carlisle,	.10	.53	.80	1.89		.20									.70		.31	.06	.08			.30	.12			.06						5.49
Drifton,		1.88		3.10		.57	•								•		1.00	.70				•	.70	1.08		.11		•		•		8.04
Emporium,	.43	.17	.16	.63	.03					.12		.74	.93	.09		.85	.12	.02		.11	.03		.23		.04	.30	.06		.01			4.99
Girardville,	1.33			2.00	1.33	.73	•	•					.18	.31		1.50	.95				•		.70			.12						8.51
Grampian,	.20				.92		.34						.40	.74	.38		.74	.34					.52			.30	.10		.07			5.47
Harrisburg, †	.20	.28	.75	1.58	.10	.07								.07	.04	1.04	.01				.10	.07	.30	.01		.04		.06				5.32
Hollidaysburg,	.45	.05	.85	.63	.76								.07	.04	.14	.67	.09				.63		.03			.26	.16			.07	.30	5.83
Huntingdon,	.23	.31	.62	1.28	.75	.21								.80	.41	.12	.53	.13			1.28	.20				.42	.12	.01			.55	7.79
Kilmer,	.35		1.10	.85	.70									.05	.01	.24	1.52				.47		.18			.11	.06				.42	6.32
Lancaster,	.17	.07	.90	3.40		.55									.20	.04	.70					.11			.02	.02	.01	.07				6.96
Lebanon,	.54	.15	.83	3.01	.11	.58								.01	.47	.04	1.05	.02			.03	.09	.91			.03	.01	.10			.07	8.05
Le Roy,	.47	.08	.10	3.16		.03									.23		1.50	.10	.02				.98			.38	.16				.15	7.76
Lewisburg,	.40		1.00	1.24	.28										.12		1.55				.11		.58			.31	.07				.70	6.42
Lock Haven,	.35	.05	1.19	1.34	.05	.58								.03	.16	.02	.80	.08			.25		.11			.31	.07				.38	4.87
Selins Grove,	.31	.45	.17	3.37		.30									.20	.02	1.28				.22	.02		.31		.19	.14				.13	6.85
South Eaton,	.35		.31	2.29										.14		1.23	.03						.34			.29	.14					5.12
State College,	.65	.17	.70	1.38	.32	.03							.26	.15	.02	.95	.09				.26		.09			.18					1.28	6.46
Wellsboro,	.12	.10	.08	2.10		.04								.65		2.16	.90				.02		.85			.16	.02				.08	6.58
Wilkes-Barre,	1.10	•	.06	1.35	.20									.11			.05						.53			.15						4.15
Wyoox,	•	•	•	•	•								.12			1.82	.48						.56			.40	.12			.16	.33	3.05
York,	.12	.35	.75	1.75	.32	.46								.01	.09	1.70	.01				.22		.40			.04		.16			.75	8.53

†U. S. Weather Bureau Stations. • Missing.

DURING MAY, 1893.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Total.
Ohio Basin.																																
Brookville,	.61	.24	..	.52	.03	.07	..	..	..	..	..	..	.05	.97	.06	.02	1.32	.04	..	..	.28	..	..	.56	..	..	.19	.06	..	..	..	5.02
Clarion,	.50	.28	..	.11	..	.09	..	..	..	..	..	..	..	1.22	.07	.16	1.60	.08	..	..	.20	..	..	.34	..	.02	.40	.02	..	..	..	5.09
Columbus,	.72	..	..	.07	..	..	..	..	..	..	..	..	.04	..	1.21	2.10	1.09	.02	..	.20	..	..	.44	..	..	.36	.01	..	..	..	.60	6.86
Confluence,	.13	.23	.21	.74	.01	2.25	..	..	..	..	..	..	..	.35	.05	.30	.65	.20	.01	..	.98	.18	..	.20	..	..	.01	.08	..	.06	..	5.64
Davis Island Dam,	.78	.06	..	..	..	.30	..	..	..	..	..	.12	..	.30	.08	.34	1.05	.08	..	1.08	.01	..	..	.25	..	..	.21	.03	..	..	..	4.70
DuBois,	.50	.21	.09	.34	.04	.09	..	..	..	..	..	.39	.56	..	.04	1.09	.09	..	..	..	.21	..	..	.34	..	.02	.25	..	..	..	..	4.66
Freeport,	.67	.15	..	.08	..	.69	..	..	..	..	..	..	.21	..	.04	.16	1.25	.15	..	..	.68	.02	..	.39	..	..	.23	..	..	..	..	4.72
Greensboro,	..	.12	.06	.19	..	.90	..	..	..	..	..	.05	.33	..	..	.50	.75	.35	..	..	1.60	.10	..	.10	..	..	.01	..	..	..	..	4.06
Immel Reservoir,	.31	..	..	.48	.62	..	..	..	..	..	..	..	..	.40	..	..	1.25	.72	..	.67	.47	..	.21	..	..	.15	..	.90	..	..	.12	5.60
Indiana,	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Johnstown,	1.01	.03	.52	.48	.55	.22	..	..	..	..	.35	.02	.19	.20	.78	.93	.08	..	..	.40	.05	..	.09	..	..	.10	.04	.03	.01	..	.09	6.26
Ligonier,	.21	.11	.54	..	.59	..	..	..	..	..	.07	.28	.21	.15	1.42	.45	.09	..	..	1.50	.09	..	.28	..	..	.16	.15	..	..	..	..	6.23
Lock No. 4,	.38	.32	.09	.08	..	.53	..	..	..	..	..	.08	.20	.09	.30	1.95	.38	.09	..	..	.75	.13	..	.55	..	..	.18	.11	..	..	.25	5.19
Mahoning,	.61	.18	..	.07	.03	.32	..	..	..	..	..	..	.51	.01	.16	1.32	.03	..	..	..	.34	.03	..	.38	..	..	.29	.05	..	..	..	4.33
Meadville,	.90	..	..	..	..	..	..	..	..	..	.17	.35	.17	.47	3.32	1.27	.05	..	..	.30	..	..	.20	..	..	.24	.03	..	..	.01	7.48
New Castle,	1.62	..	..	.28	..	..	..	..	..	..	.18	.33	..	..	.90	2.24	..	..	..	.20	..	..	.32	..	..	.16	..	..	..	..	..	6.23
Oil City,	.82	1.16	..	.05	..	..	..	..	..	..	..	.04	.74	.15	.36	2.13	.03	..	..	..	.17	..	.19	..	..	.32	..	..	..	..	..	6.15
Parker's Landing,	.67	.49	..	.05	..	.32	..	..	..	..	..	.68	.18	.08	2.10	.02	..	..	..	.29	..	..	.30	..	.03	.16	.13	..	..	..	.13	5.98
Pittsburg,†	.56	..	..	.02	.51	.01	..	..	..	..	.14	.09	.02	.10	.09	.55	.03	..	1.02	.08	..	..	.13	..	..	.16	.01	..	.01	..	.13	4.50
Ridgway,	.40	..	.32	..	..	..	..	..	..	..	.72	.80	.11	..	.82	.01	..	..	.16	..	.10	..	.45	..	..	.30	.05	..	..	..	..	4.14
Saegertown,	.89	..	..	..	..	..	..	..	..	..	.20	.45	.02	1.49	3.20	1.96	.06	..	..	.30	..	..	..	..	..	.25	.01	..	..	..	.06	8.89
Saltsburg,	.60	.11	..	.19	..	.83	..	..	..	..	..	..	.13	.08	.30	.95	.22	.03	..	..	.82	..	..	.54	..	..	.15	..	..	..	.06	4.94
Smethport,	.90	..	..	.70	..	..	..	..	..	..	.60	.75	..	..	.70	.10	..	..	..	.15	..	..	.45	..	..	.30	.10	..	..	..	.15	4.90
Somerset,	.65	.17	1.00	.55	1.00	..	..	..	..	..	.15	.10	.05	.35	.40	.50	..	..	..	.65	.52	..	.20	..	..	.10	.05	..	.06	..	.80	7.30
Stoyestown,	.30	.47	.22	1.13	.15	.80	..	..	..	..	..	.12	.19	.16	.33	.20	.16	..	..	.83	.57	..	.12	.10	..	..	.05	..	..	.13	.31	6.74
Uniontown,	.29	.05	.23	.08	1.05	.03	..	..	..	..	..	.17	..	.10	1.14	.57	.18	..	..	.98	.42	..	.25	..	..	.06	.07	..	..	.28	..	5.68
Warren,	1.18	.73	..	.26	..	..	..	..	..	..	..	.03	.78	.33	.39	1.72	.07	..	..	..	.10	..	..	.37	..	..	.33	.04	..	..	..	6.98
West Newton,	.50	.45	..	.10	..	.48	..	..	..	..	..	.20	.20	.02	.25	1.01	.50	.02	..	..	.62	.05	..	.05	..	.13	.13	.19	..	.02	.35	5.54
Potomac Basin.																																
Chambersburg,	..	.21	..	1.75	.97	..	..	..	..	..	..	.50	..	..	1.05	..	..	..	..	..	.83	..	.57	..	..	.07	..	.08	..	.27	..	6.24
McConnellsburg,	.39	..	.90	.83	.78	.16	..	..	..	..	..	.42	.07	.20	.70	..	..	..	..	.40	.74	..	.22	..	..	.06	..	..	.10	..	.23	6.20
Lake Basin.																																
Erie,†	.84	..	..	..	.01	.03	..	..	..	..	..	.18	.13	.19	.18	3.68	2.33	.14	..	..	..	..	.16	..	..	.06	.03	..	..	..	.10	7.99

MEAN TEMPERATURE, RAINFALL AND PREV



EVAILING WIND DIRECTION FOR MAY. 1893

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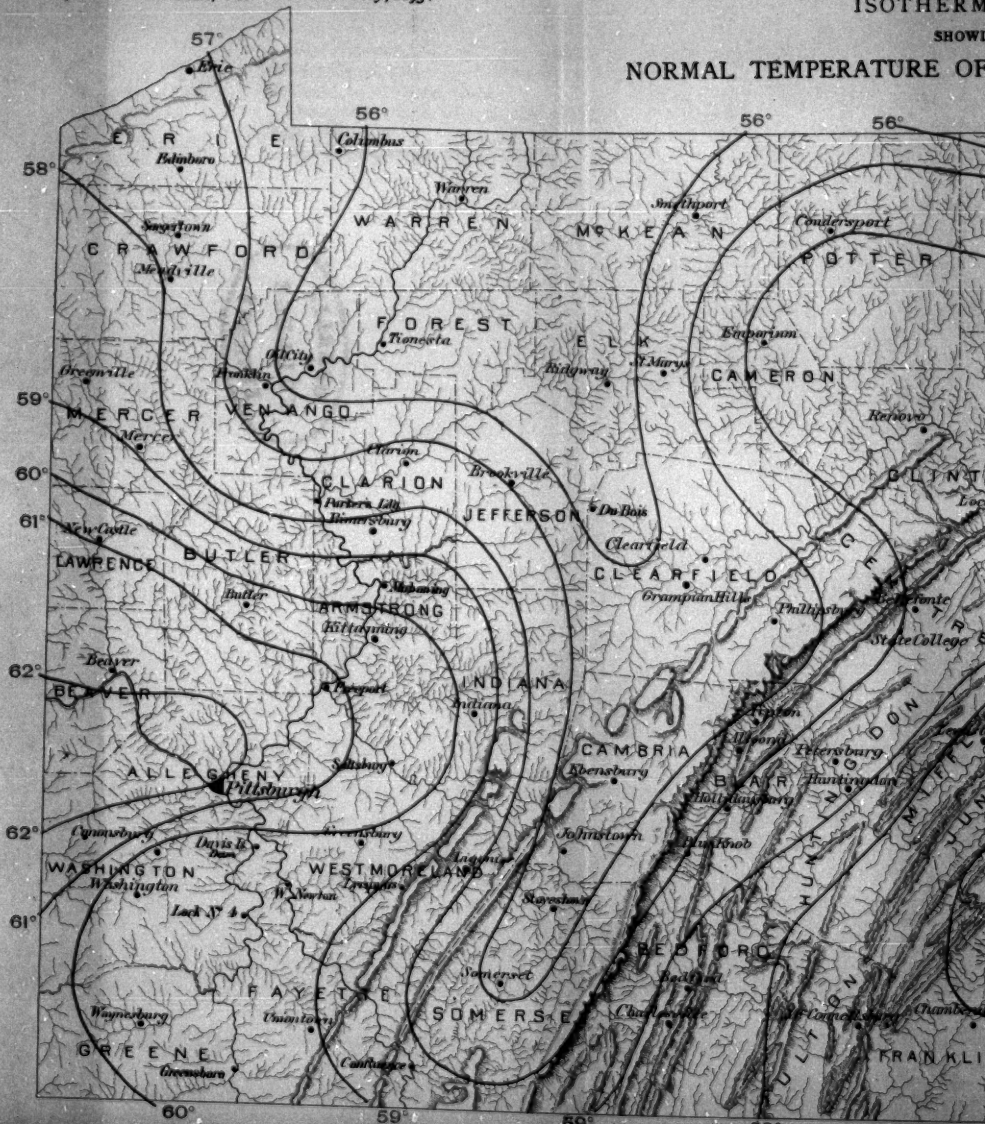
NORMAL TEMPERATURE OF



MAL LINES,

WING THE

OF PENNSYLVANIA FOR MAY.

State Weather Service.

Solar Halo.—Le Roy, 23d, 31st; Quakertown, 13th; Lock Haven, 15th; Philadelphia, 2d, 15th, 23d; Centennial Avenue, 2d, 15th, 23d; Wellsboro, 14th, 24th, 31st; Dyberry, 8th.

Lunar Halo.—Lock Haven, 20th; Meadville, 28th; Carlisle, 21st; Lancaster, 30th.

Meteors.—Meadville, 5th, 8th, 24th.

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Solar Halo.—Le Roy, 23d, 31st; Quakertown, 13th; Lock Haven, 15th; Philadelphia, 2d, 15th, 23d; Centennial Avenue, 2d, 15th, 23d; Wellsboro, 14th, 24th, 31st; Dyberry, 8th.

Lunar Halo.—Lock Haven, 20th; Meadville, 28th; Carlisle, 21st; Lancaster, 30th.

Meteors.—Meadville, 5th, 8th, 24th.